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MEDICAL CENTER  
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# Function and Structure in Nuclear Medicine

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USA

# Nuclear Medicine

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- Radioactive material is administered into the patient body
- Photons emitted in the patients are detected by a scintillator
- Distribution of the radioactivity in the patient body is reconstructed from projections

# Radioactivity

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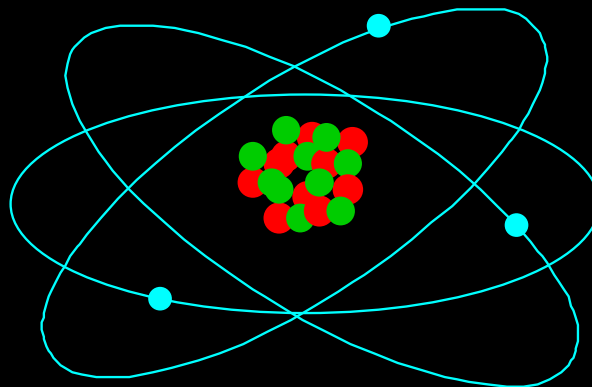


Maria Skłodowska-Curie (1867-1934)

# Radioactivity

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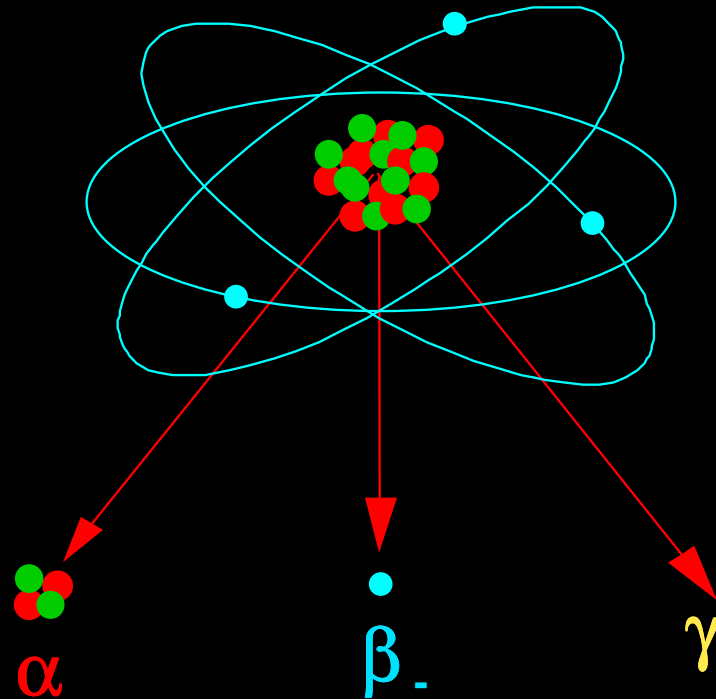
Process that involves the nucleus



# Radioactivity

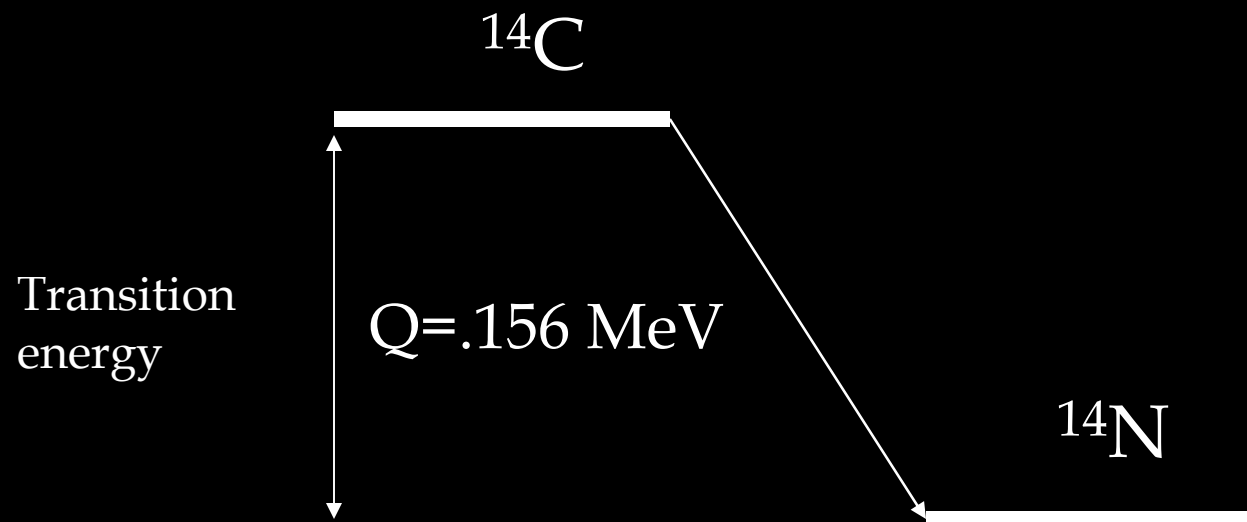
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Energy state of nucleus changes



# Radioactivity

## Decay scheme diagram for $^{14}\text{C}$

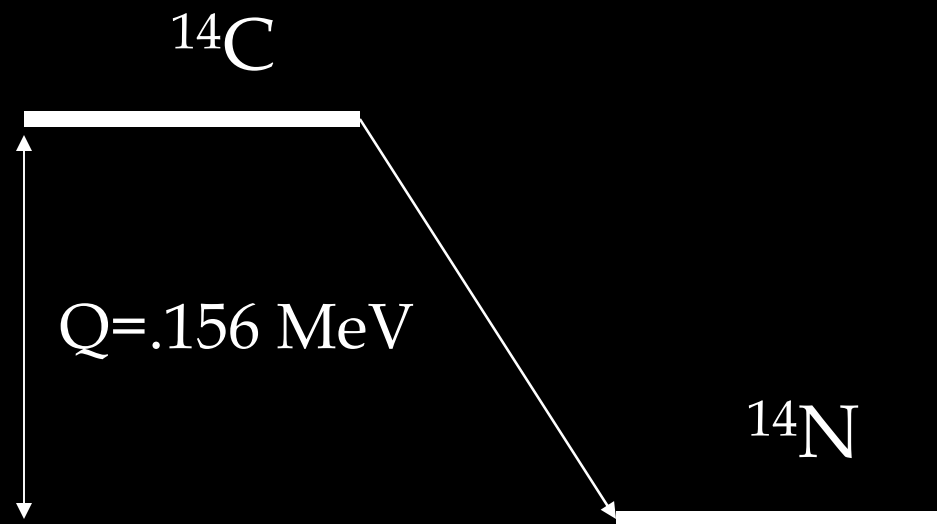


- Numbers of protons and neutrons change
- $\beta^-$  particle is emitted

# Radioactivity

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## Decay scheme diagram for $^{14}\text{C}$



$^{14}\text{C}$  is not good for imaging because the decay does not produce photons

# Nuclear Medicine

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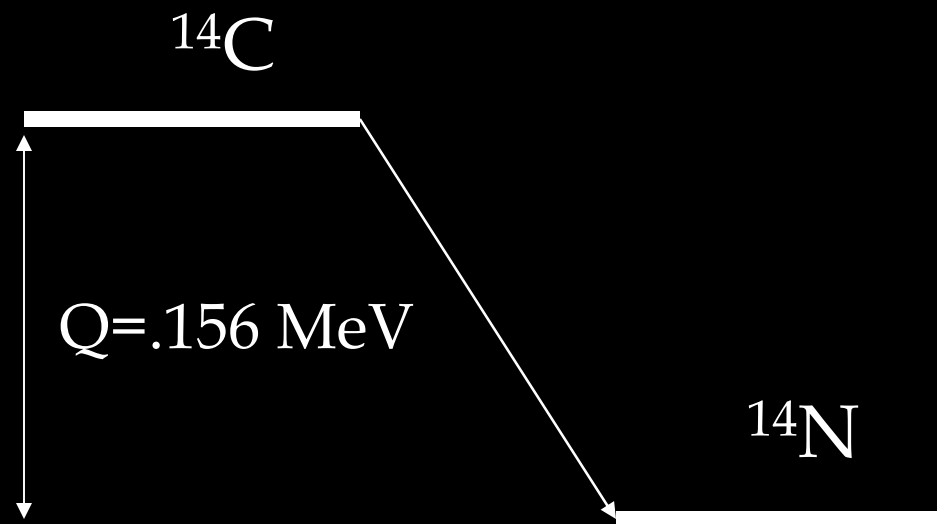
- Radioactive material that emits **photons** is administered into the patient body
- Photons coming from the patients are detected by a scintillator
- Distribution of the radioactivity in the patient body is reconstructed from projections



# Radioactivity

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## Decay scheme diagram for $^{14}\text{C}$



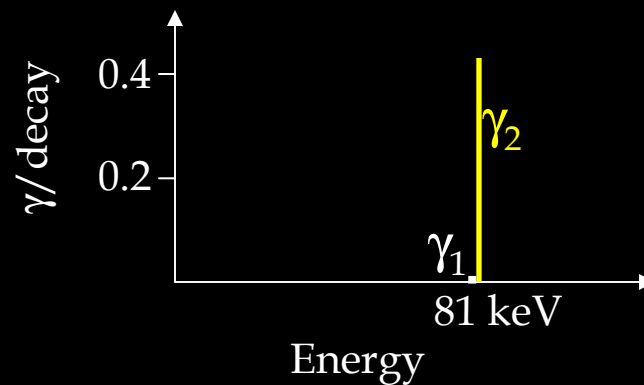
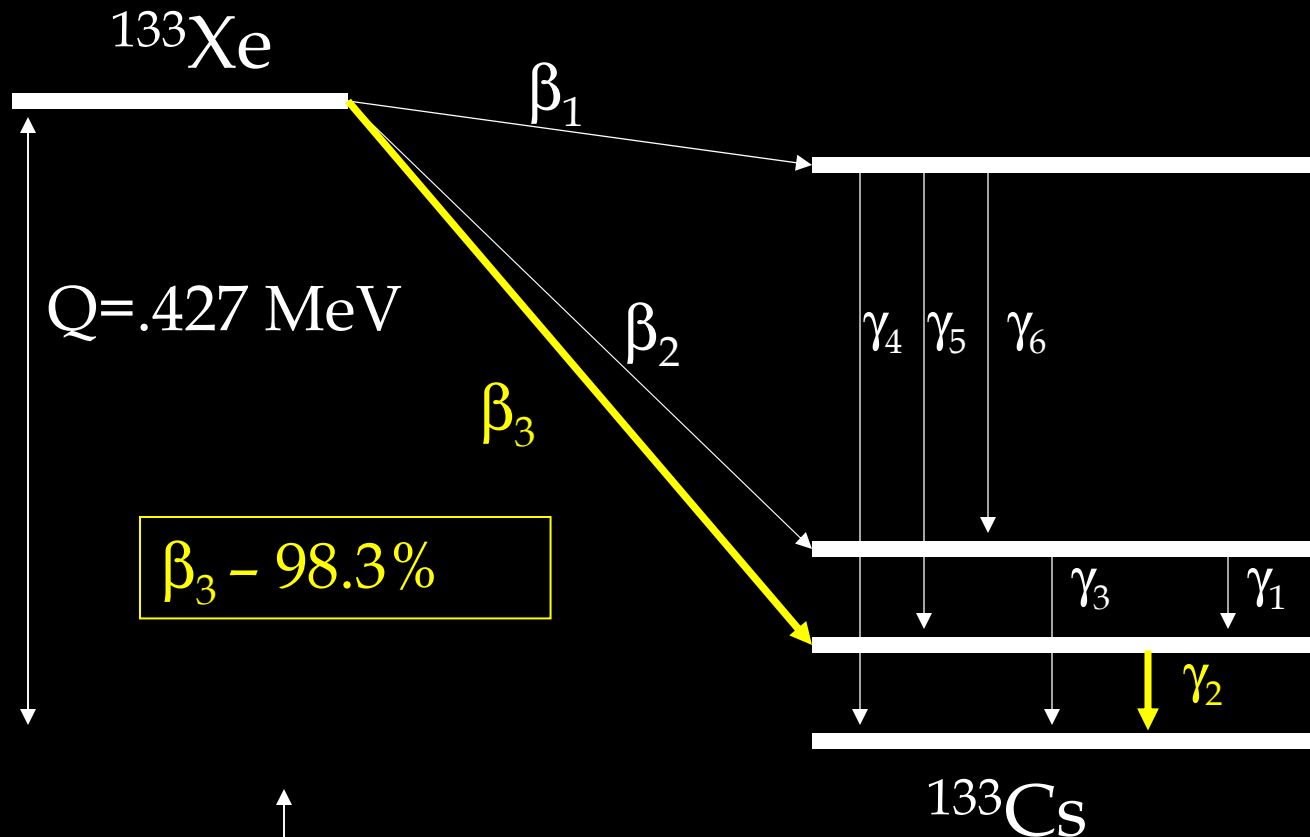
$^{14}\text{C}$  not only does not produce useful photons  
but also its half-life is 5730 years

# Nuclear Medicine

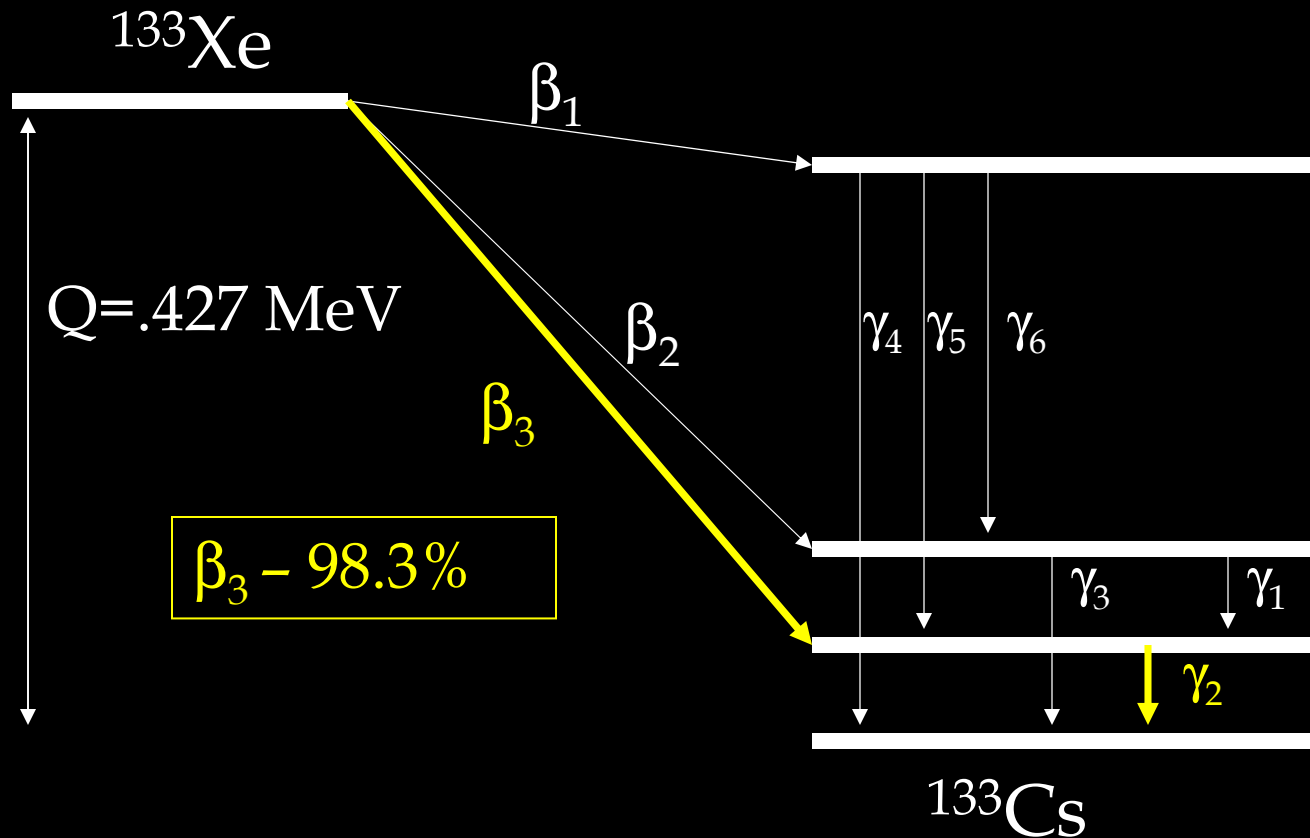
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- Radioactive material **with half-life in order of few hours** that emits **photons** is administered into the patient body
- Photons coming from the patients are detected by a scintillator
- Distribution of the radioactivity in the patient body is reconstructed from projections

# Decay scheme diagram for $^{133}\text{Xe}$

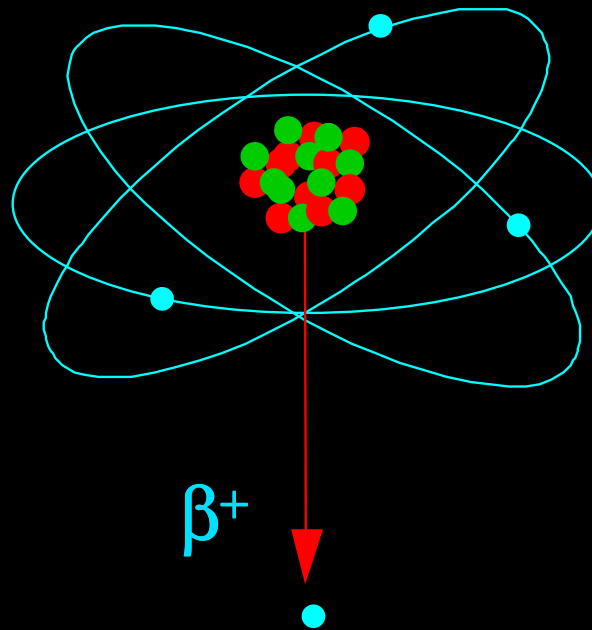


## Decay scheme diagram for $^{133}\text{Xe}$

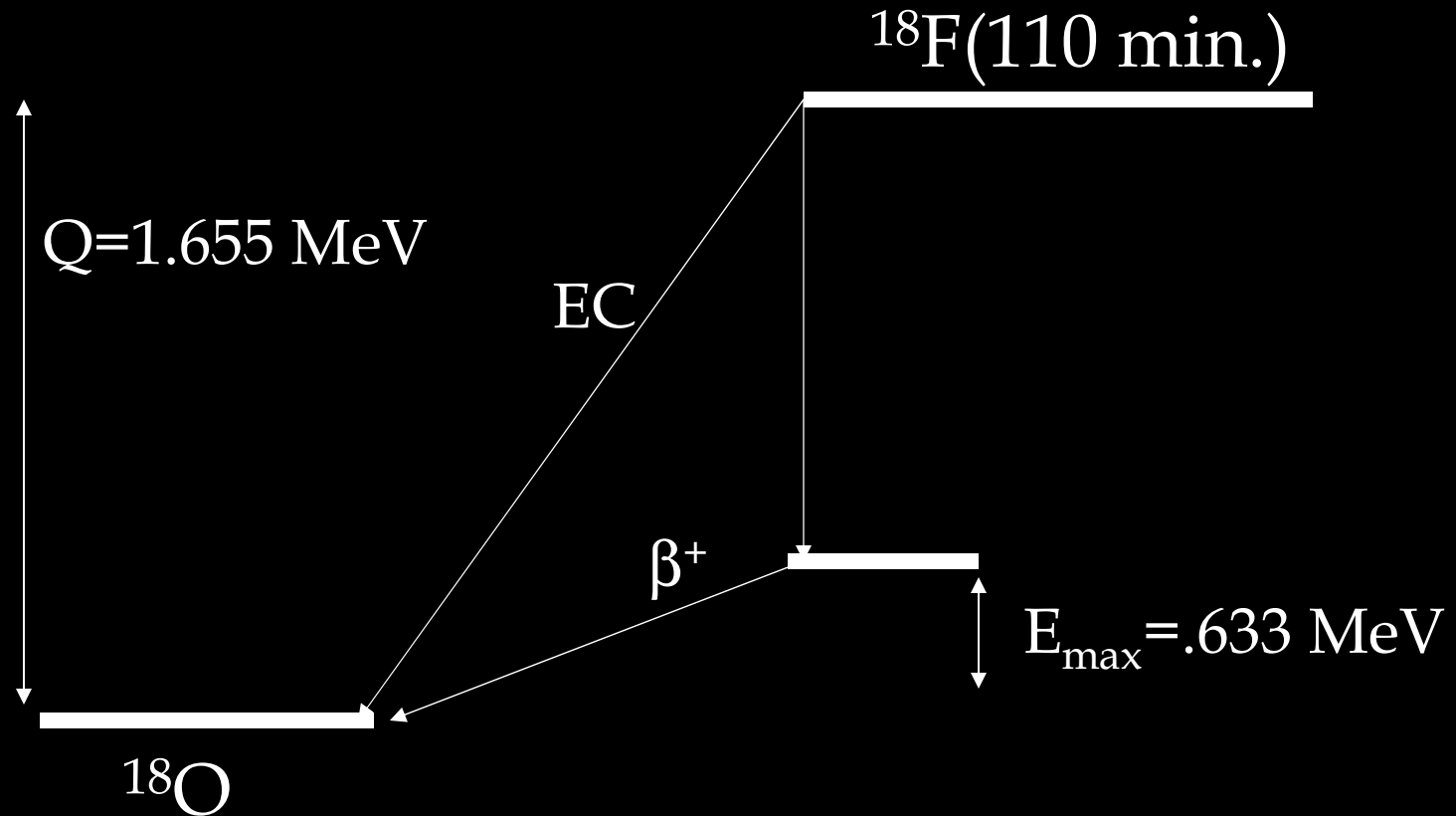


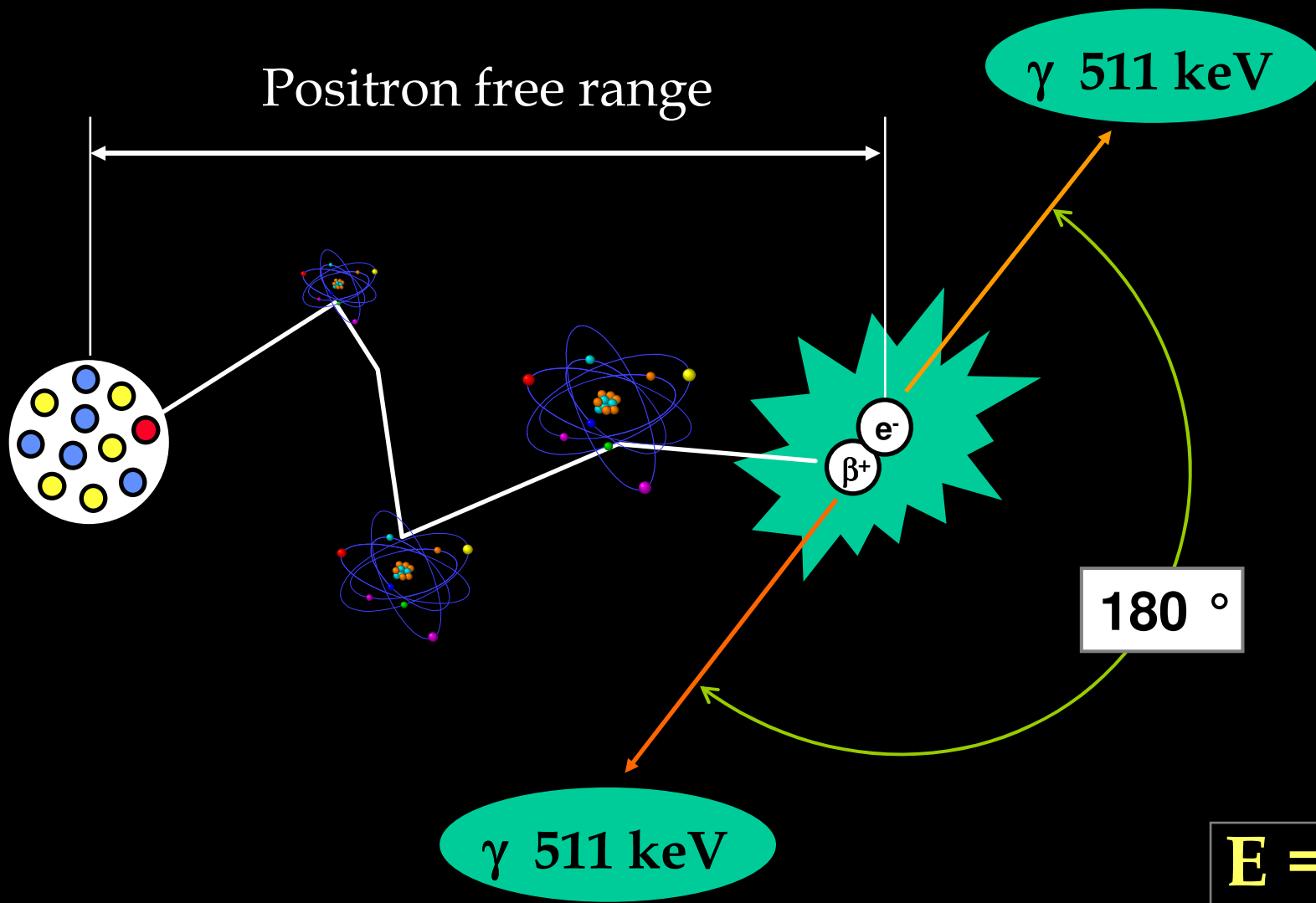
Half-life 5.2 days

## What about positron emitters ?



## Decay scheme diagram for $^{18}\text{F}$





Isotope	Half-life minutes	$E_{\max} \beta^+$ keV	Positron free range mm
$^{11}\text{C}$	21	960	4,1
$^{13}\text{N}$	10	1200	5,4
$^{15}\text{O}$	2	1730	8,2
$^{18}\text{F}$	110	630	2,6



# Nuclear Medicine

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- Radioactive material **with half-life in order of few hours** that emits **gamma photons** is administered into a patient body
- Photons coming from the patients are detected by a scintillator
- Distribution of the radioactivity in the patient body is reconstructed from projections

# Detection

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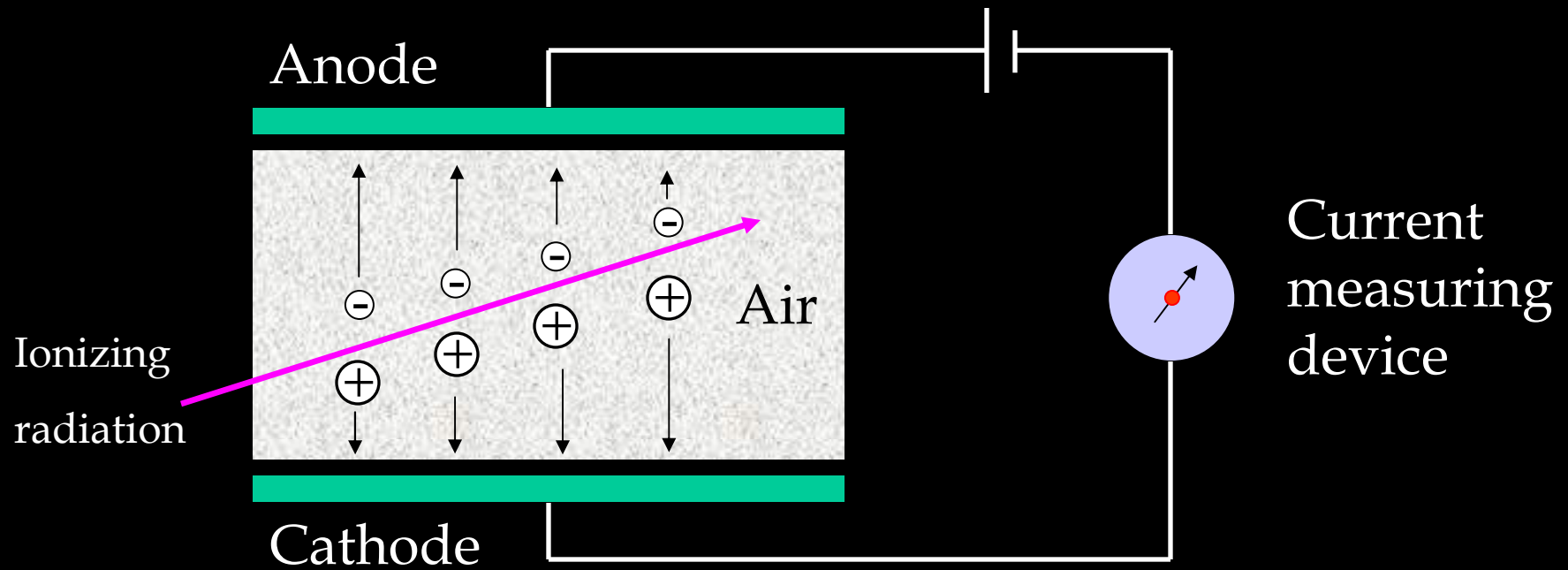
- Photon energy cannot be too high because photons would have too high penetration
  - Hard to detect
  - Safety issues
- Photon energy cannot be too low because photons would have too low penetration

# Nuclear Medicine

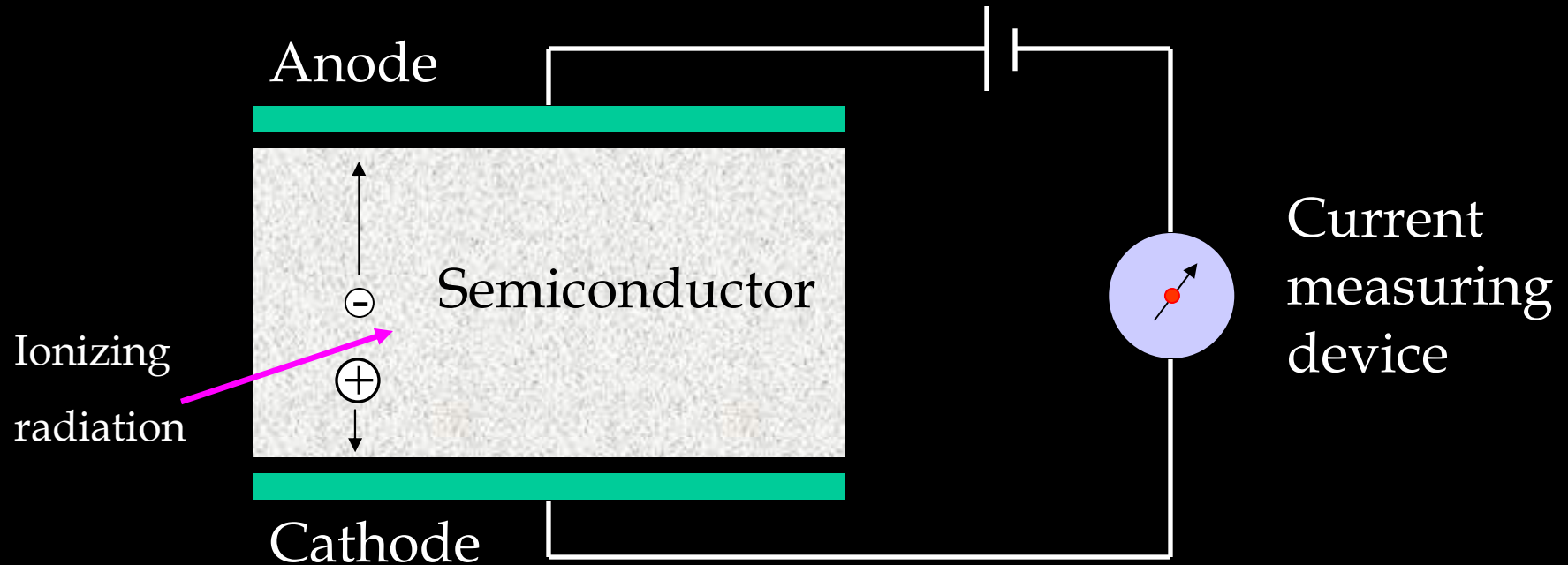
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- Radioactive material with half-life in order of few hours that emits gamma photons is administered into the patient body
- Photons with energies ranging from 50 keV to 600 keV coming from the patients are detected by a scintillator
- Distribution of the radioactivity in the patient body is reconstructed from projections

# Gas Filled Detectors



# Solid State Detectors

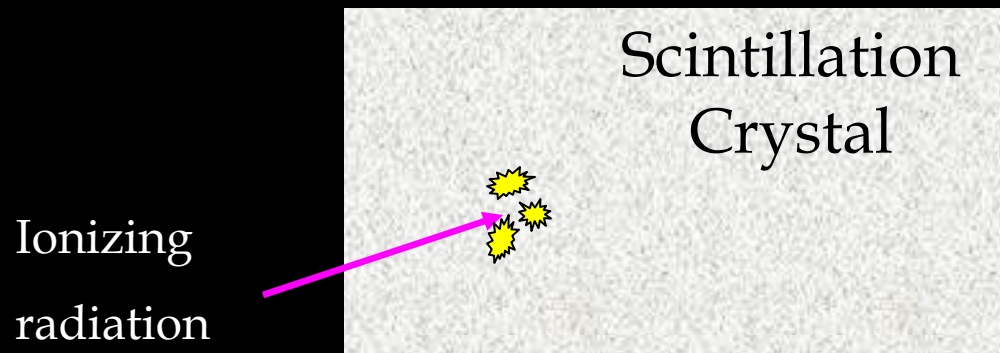


Silicon (Si), Germanium (Ge), Cadmium Telluride (CdTe), **Cadmium Zinc Telluride (CZT)**

# Scintillation Detectors

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Nuclear Medicine uses scintillation detectors



Interaction of a gamma photon with the crystal produces visible light (several hundred photons)

# Crystals Commonly used in NM

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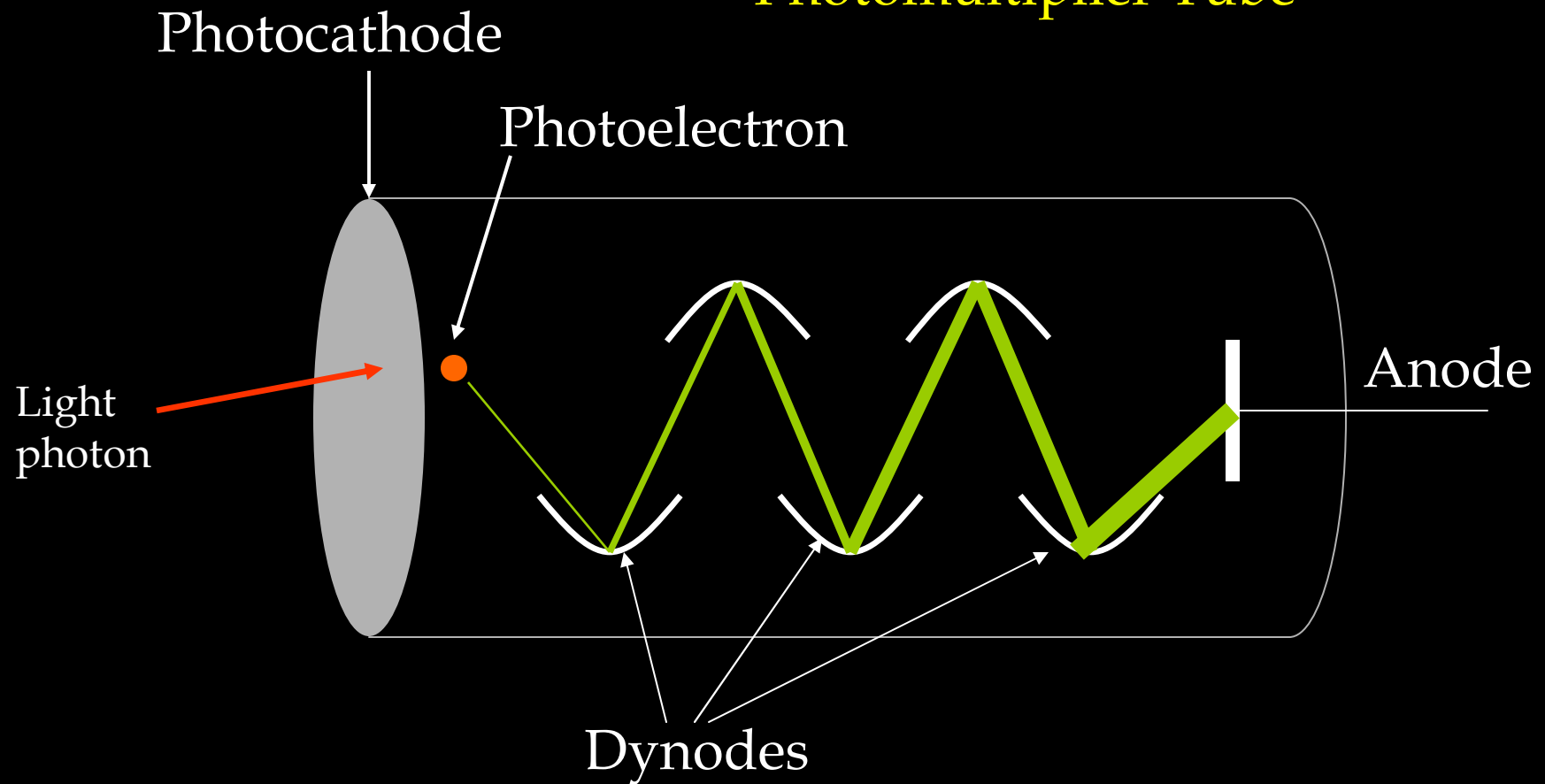
Property	NaI(Tl)	BGO <sup>†</sup>	LSO <sup>‡</sup>
Density (g/cm <sup>3</sup> )	3.67	7.13	7.40
Effective Atomic #	50	74	66
Decay Time (ns)	230	300	40
Photon Yield (per keV)	230	300	40

<sup>†</sup>Bismuth germanate Bi<sub>4</sub>Ge<sub>3</sub>O<sub>12</sub>

<sup>‡</sup>Lutetium oxyorthosilicate Lu<sub>2</sub>(SiO<sub>4</sub>)O

# Scintillation Detectors

## Photomultiplier Tube

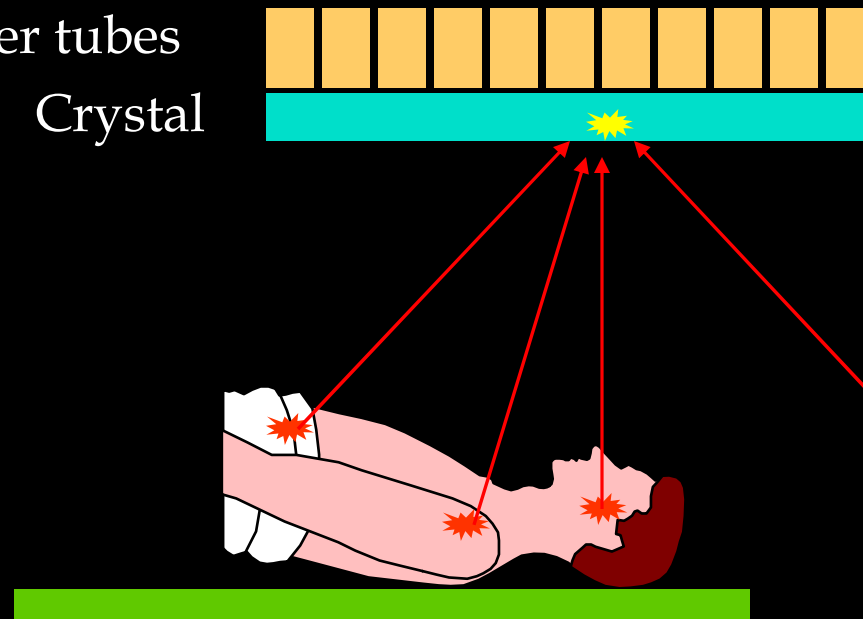




# Direction of incoming photon

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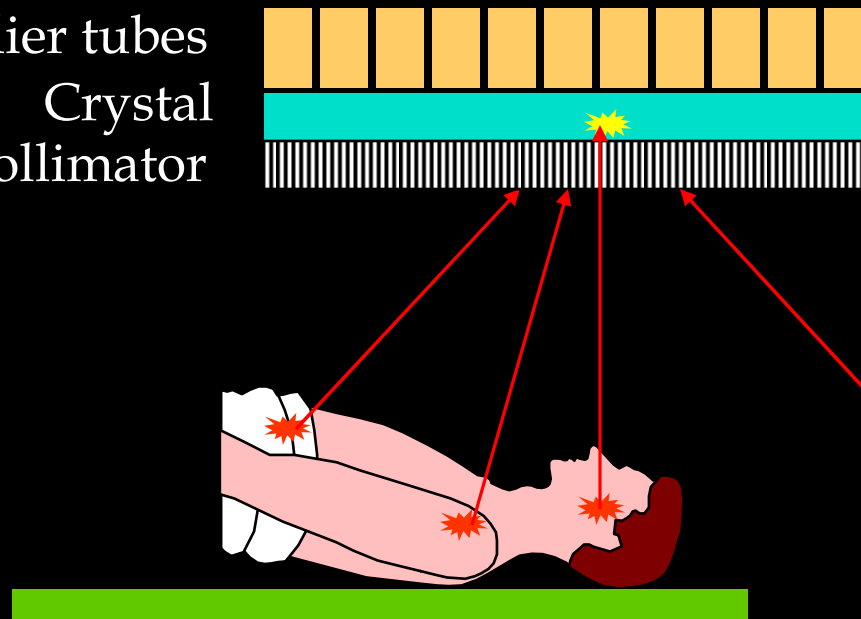
Photomultiplier tubes  
Crystal



# Direction of incoming photon

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Photomultiplier tubes  
Crystal  
Lead collimator



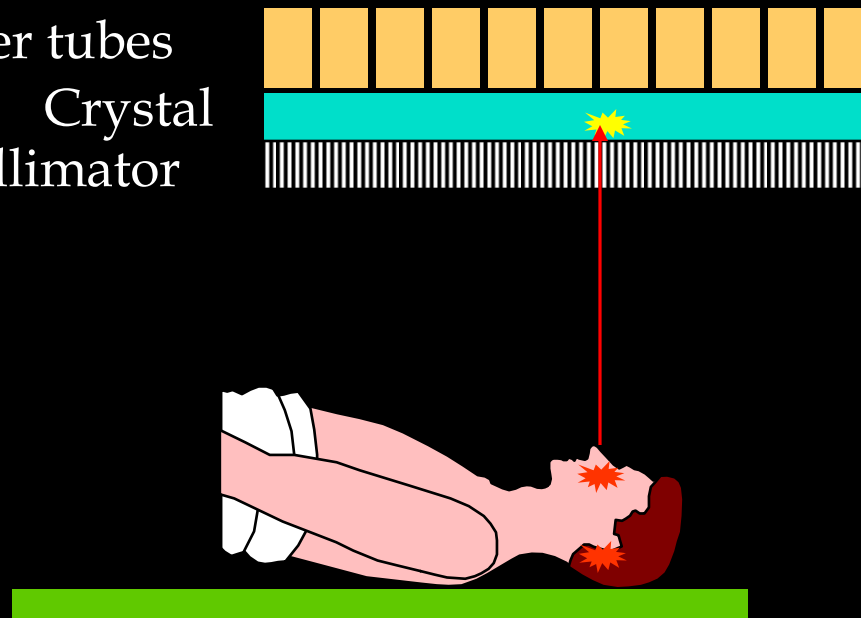
# Direction of incoming photon

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Photomultiplier tubes

Crystal

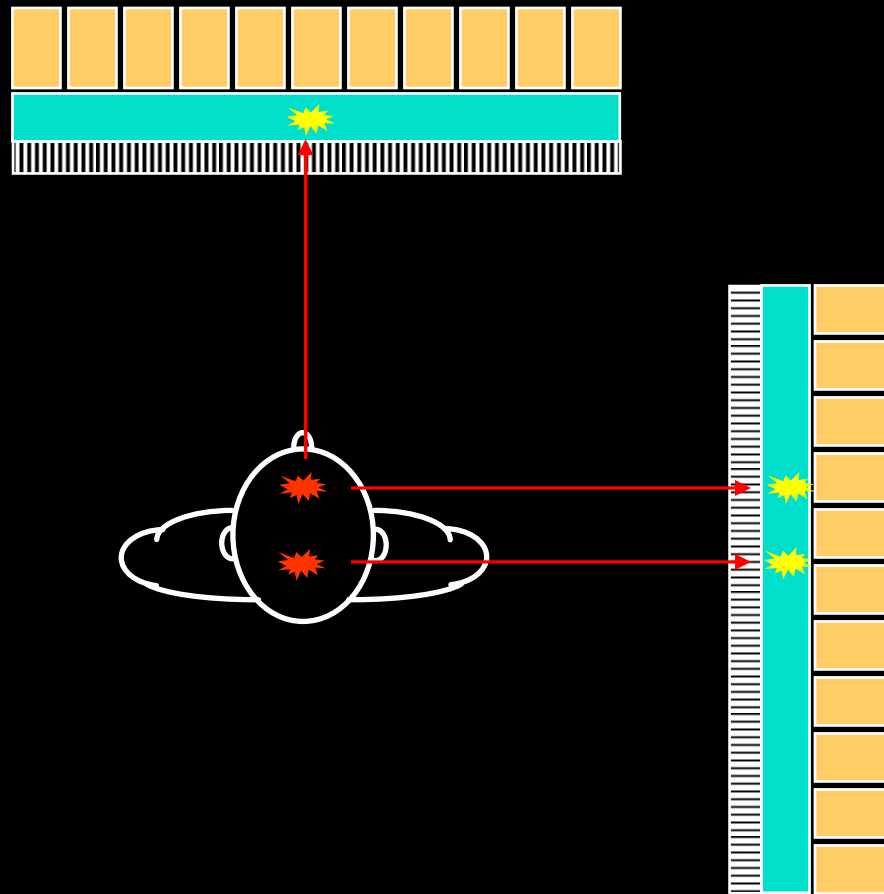
Lead collimator



The ambiguity is resolved by performing tomography *i.e.* rotating detector around patient

# Single Photon Emission Tomography

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# Single Photon Emission Computed Tomography

## SPECT

Typically:

- 60 projections are acquired around patient over at least  $180^\circ$
- It takes 1 minute per projection to acquire enough photon counts

## 2 detector camera



## 3 detector camera



SPECT is not a very efficient technique

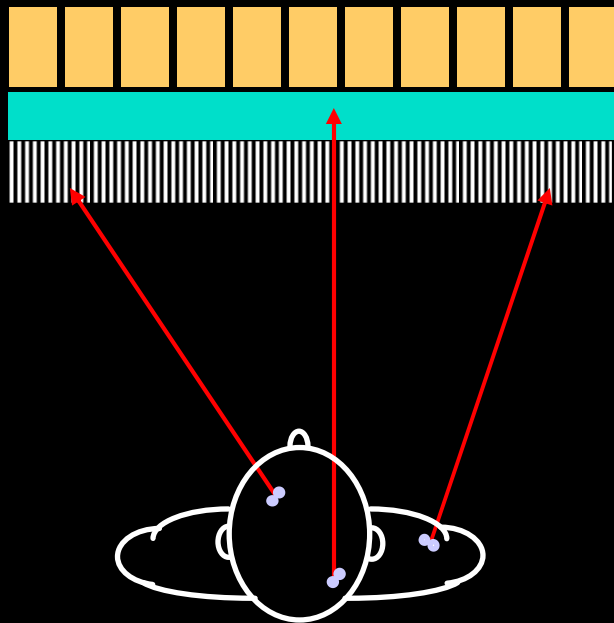


SPECT is not a very efficient technique

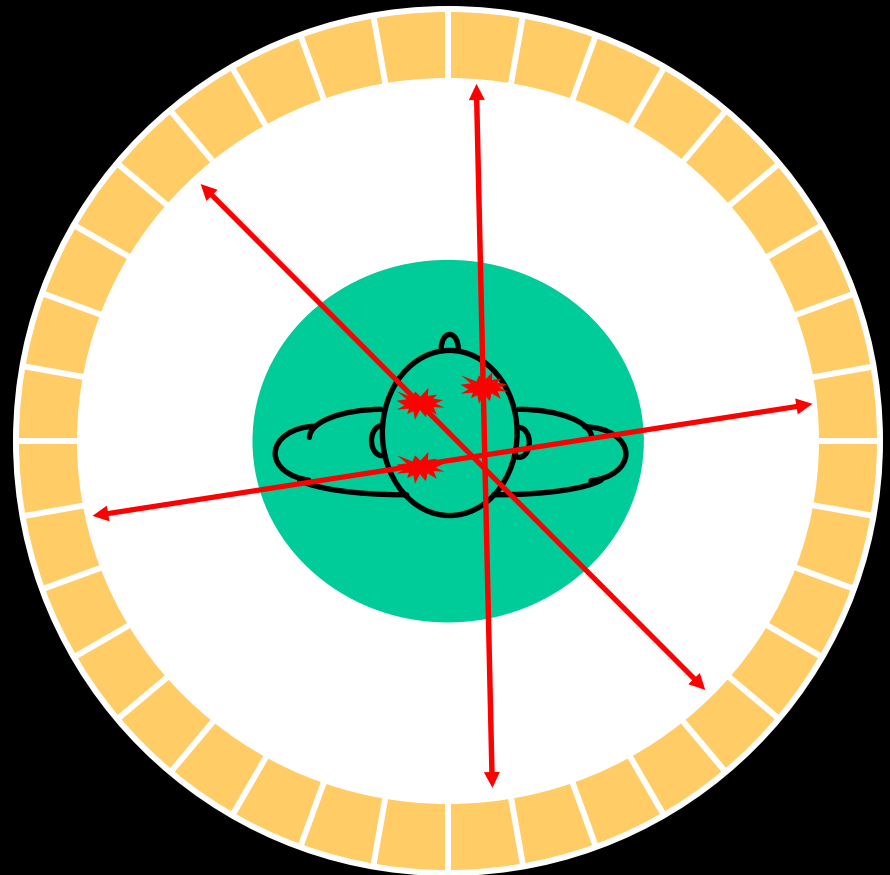
- Only 1 in every 10,000 gamma photons is detected
- Resolution is only about 1cm

# Positron Emission Tomography (PET)

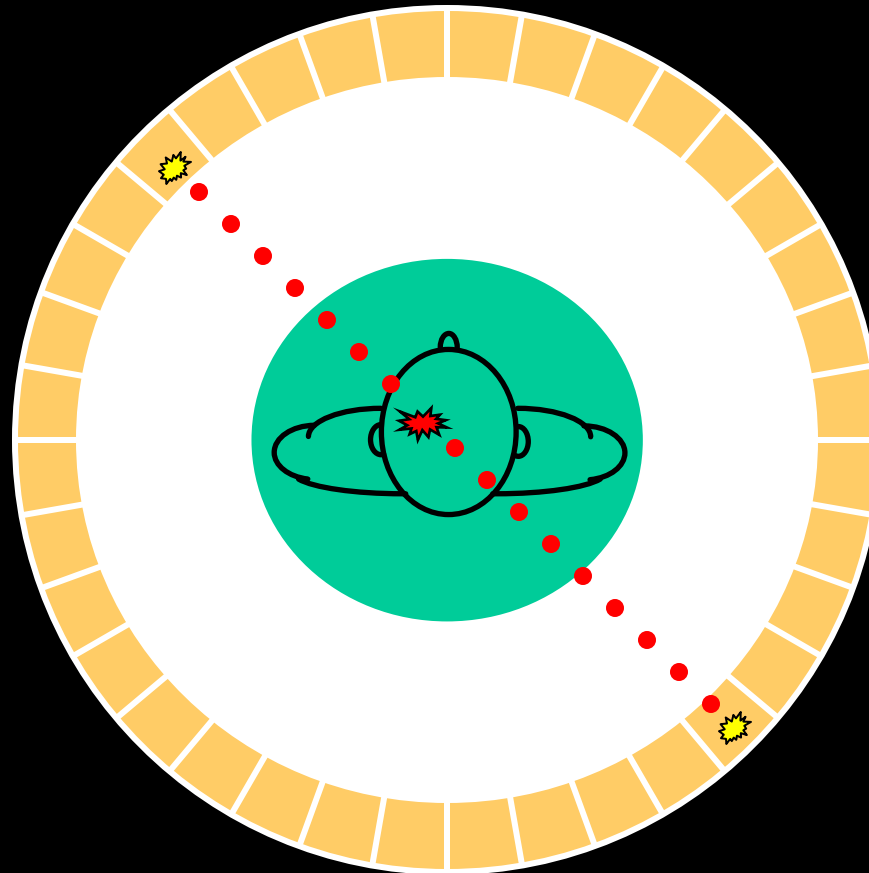
## SPECT

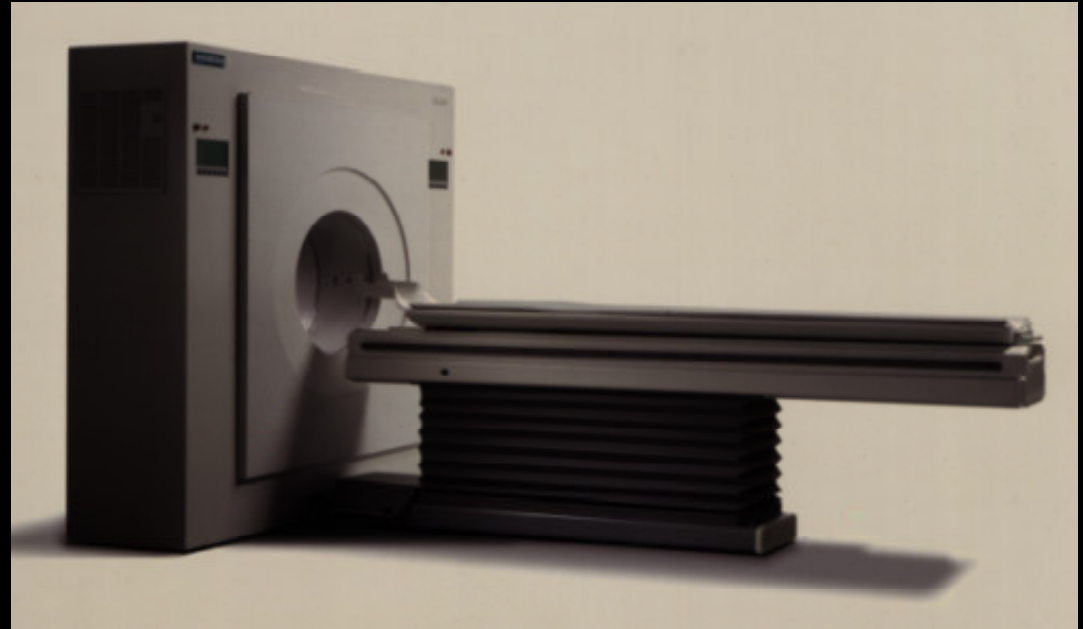
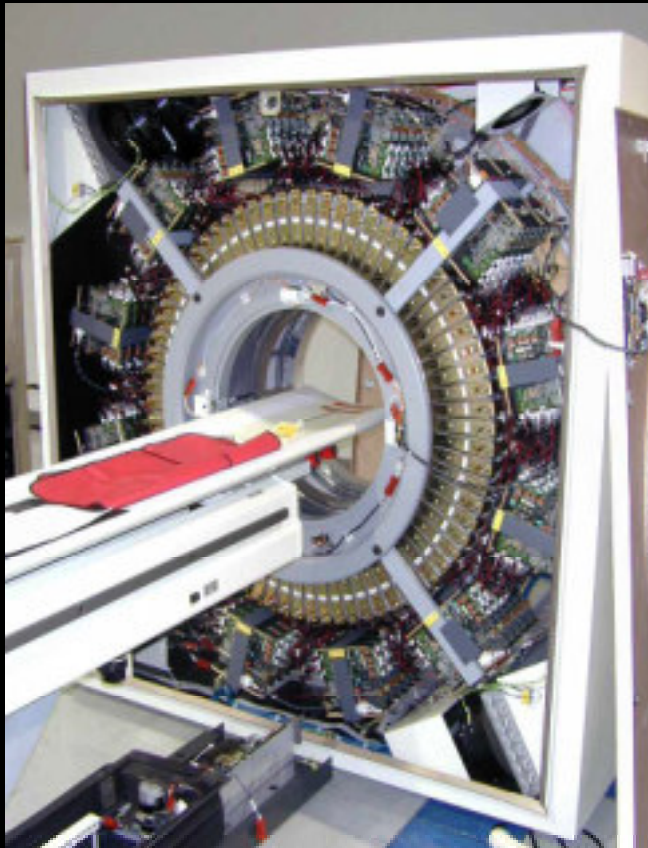


## PET



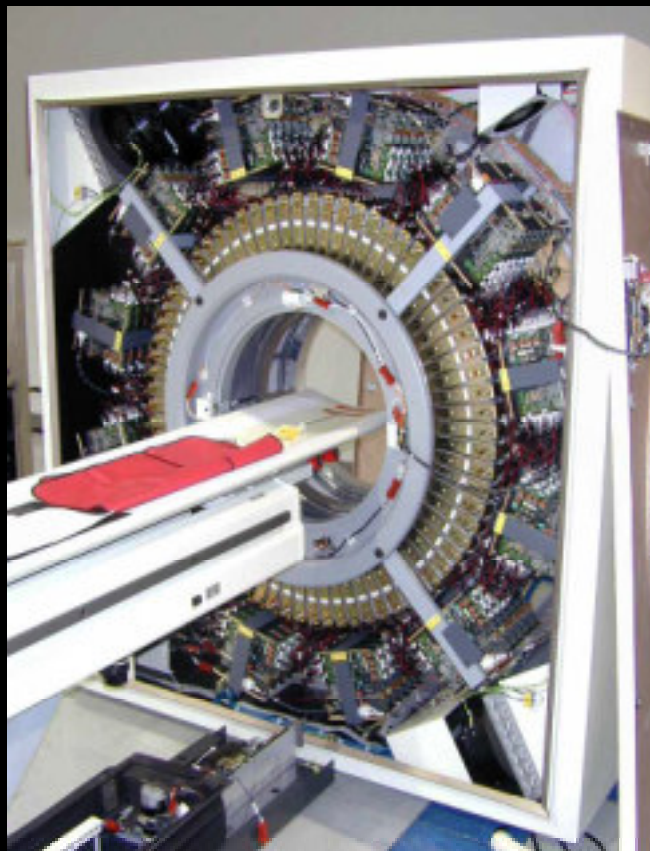
# PET



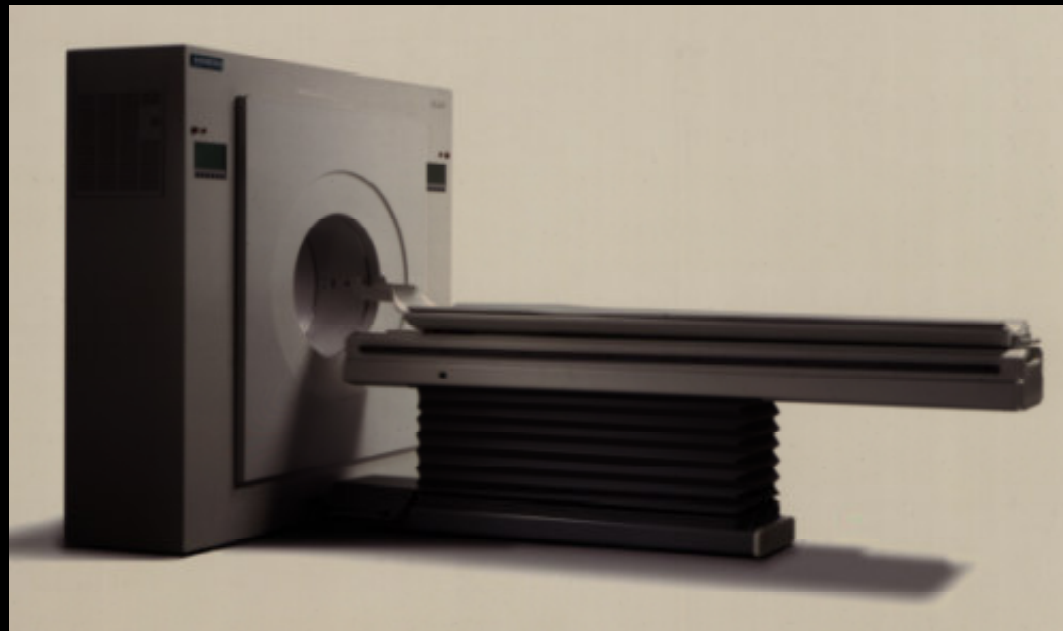


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PET



PET

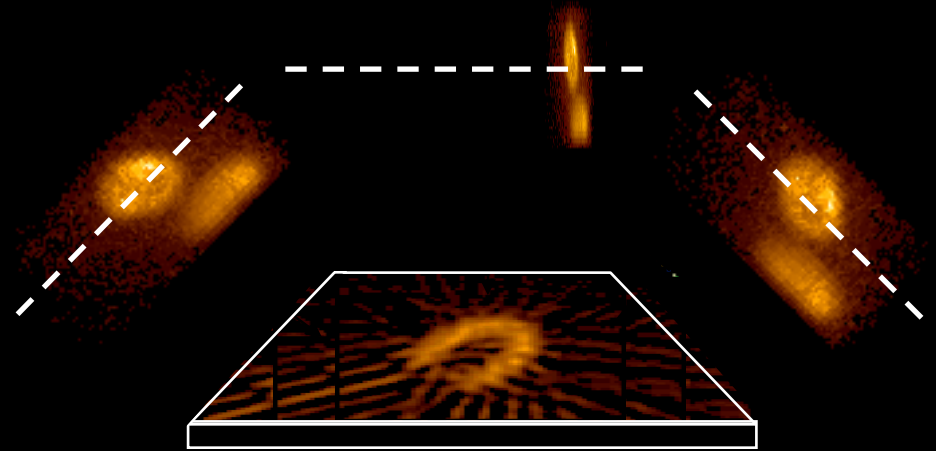
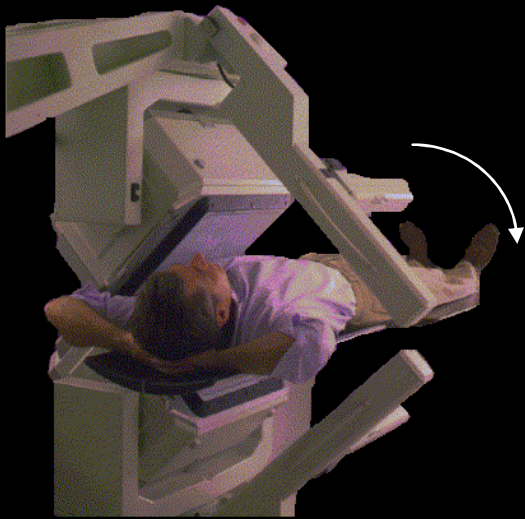


SPECT

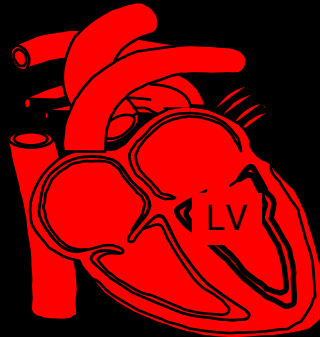


# Examples of NM images

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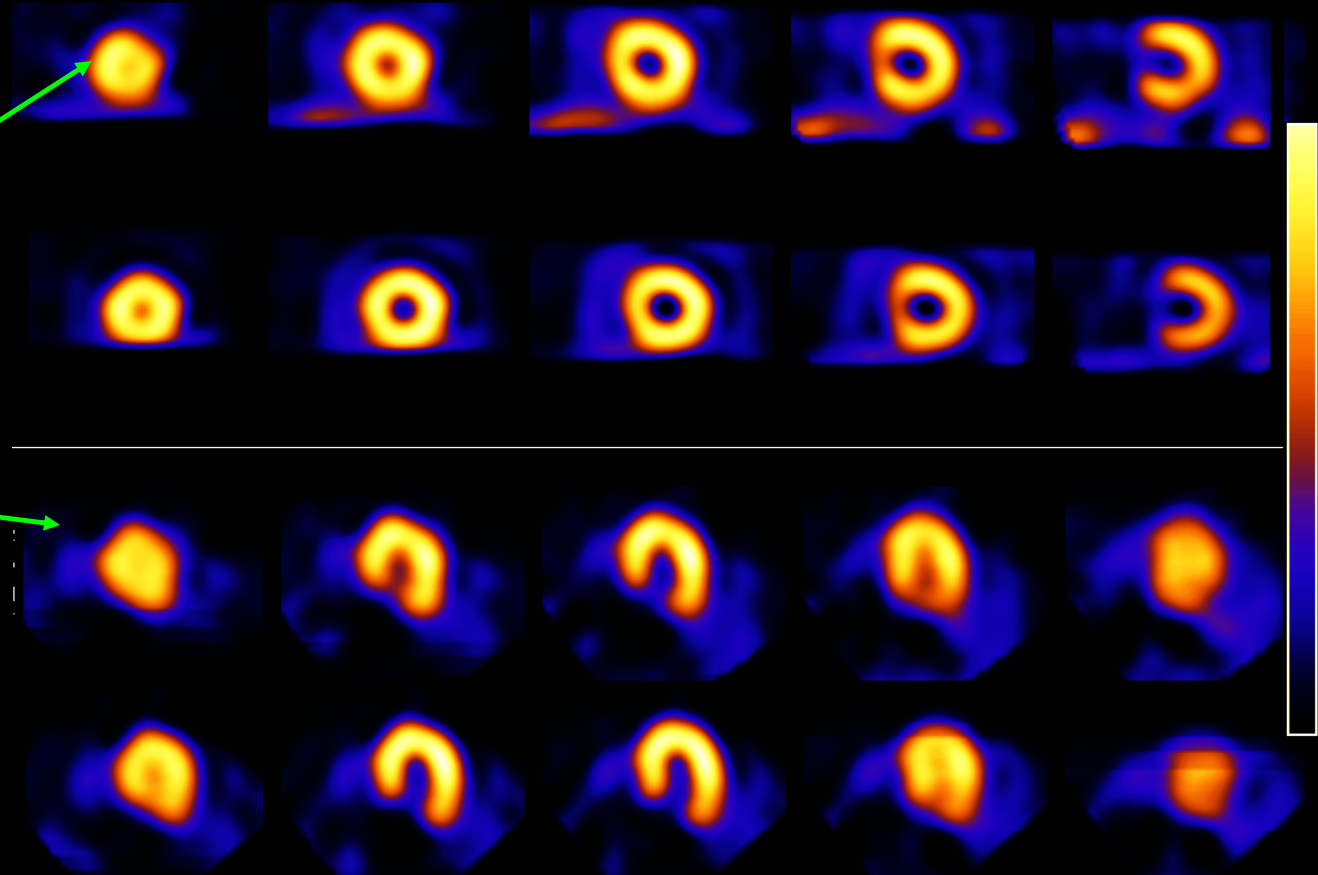
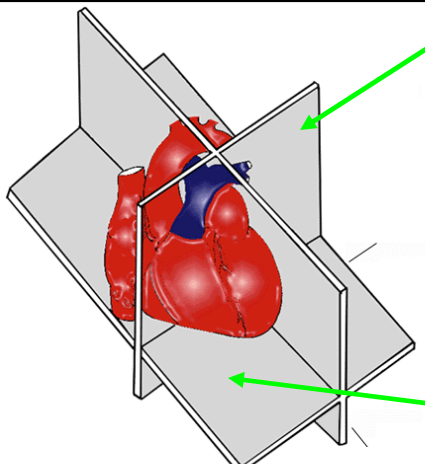
## SPECT Cardiac Imaging



- Perfusion
- Viability

# Cardiac SPECT

## Normal Study (Var. 2 -Short Septum) Tc-99m SESTAMIBI



Brigham & Women's Hospital



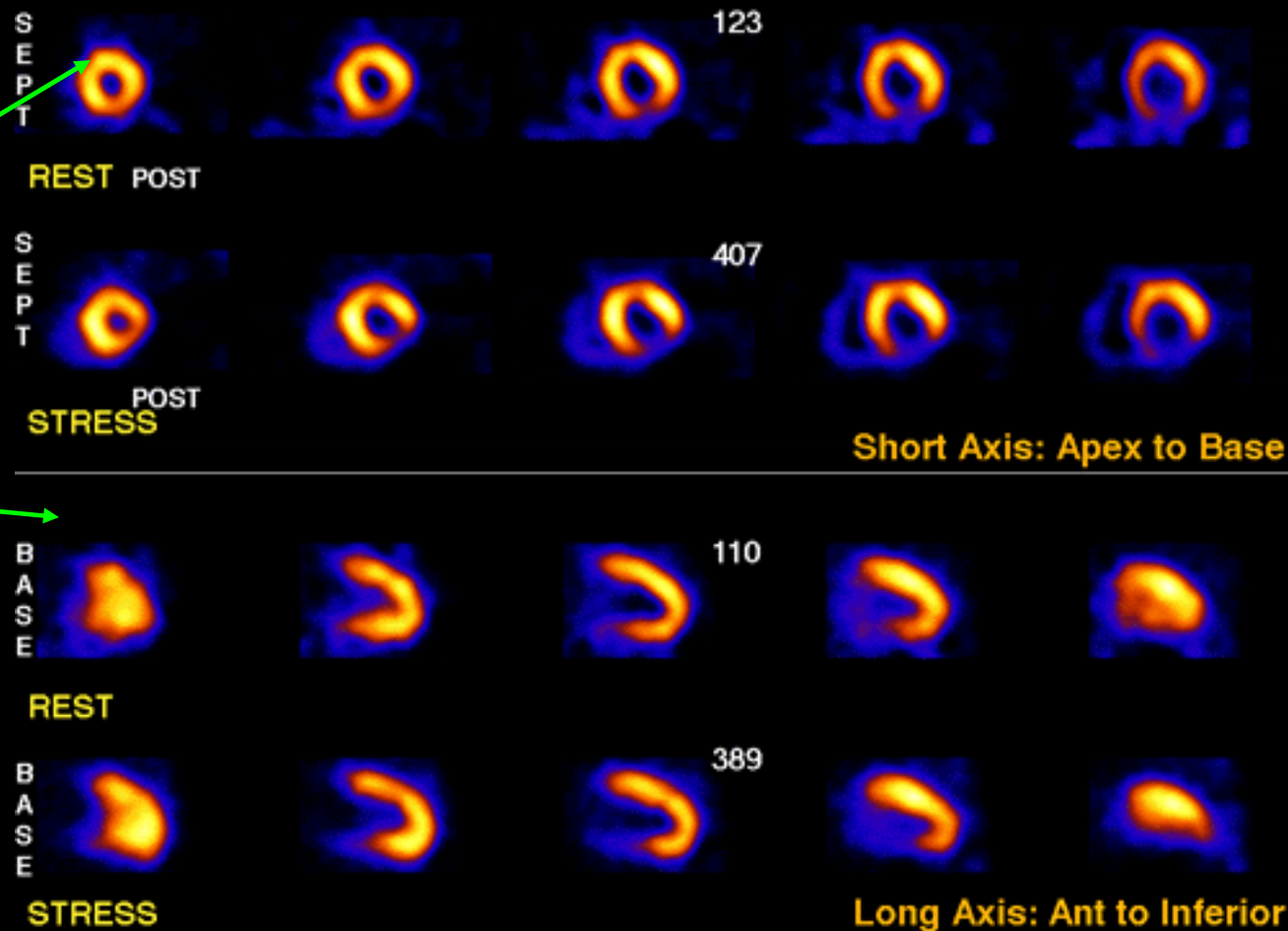
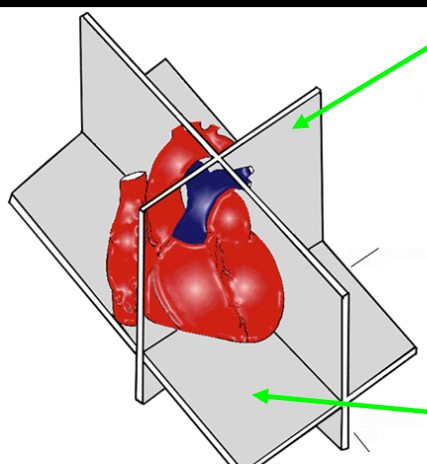
Harvard Medical School



# Cardiac SPECT

## Transmural Inferior Wall MI

Tc-99m SESTAMIBI



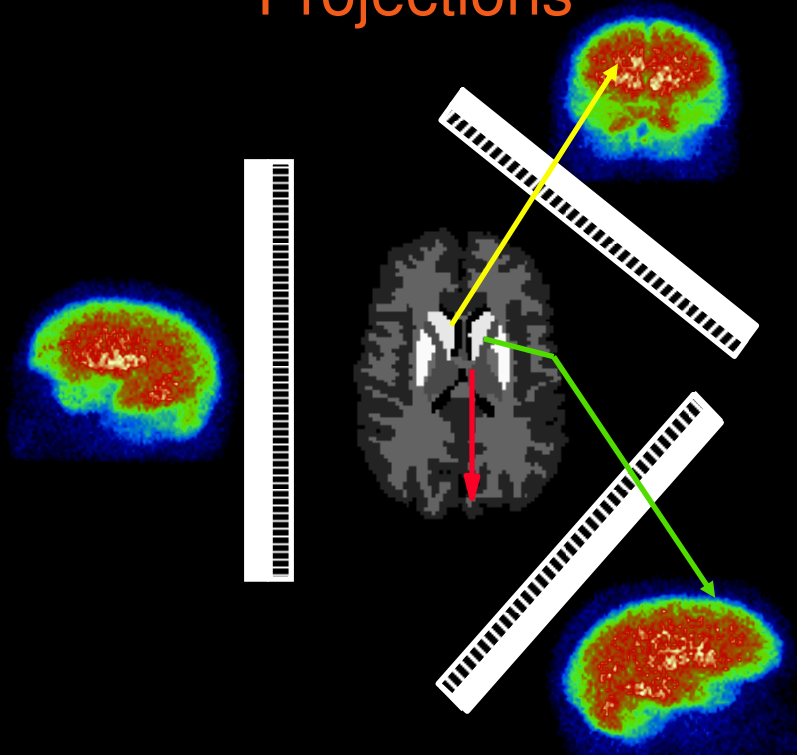
Brigham & Women's Hospital



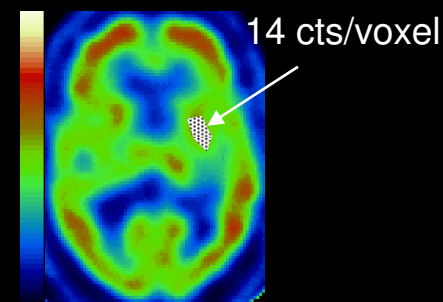
Harvard Medical School

# Brain SPECT

## Projections



## Reconstruction

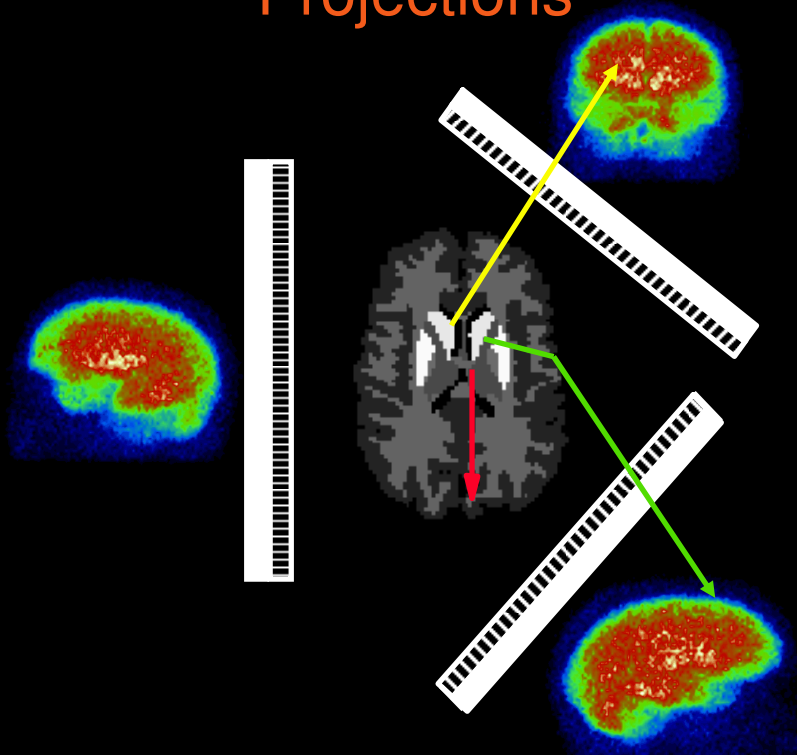


- primary photon (collimator response)
- scattered photon (scatter and collimator response )
- absorbed photon (absorption)

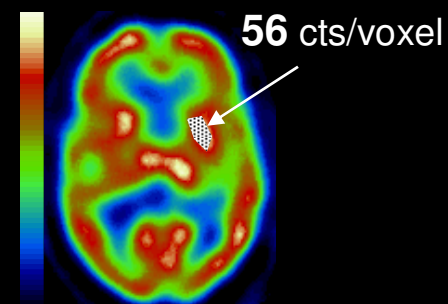
G. El Fakhri et al. "Respective roles of scatter, attenuation, collimator response and partial volume effect in cardiac SPECT quantitation: a Monte Carlo study", *E J Nucl Med* 1999, vol. 26, pp. 437-446.

# Brain SPECT

## Projections



## Reconstruction with corrections



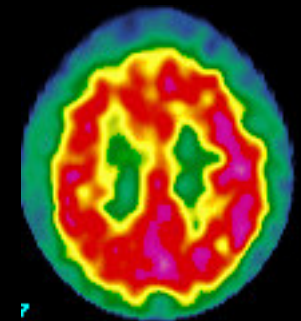
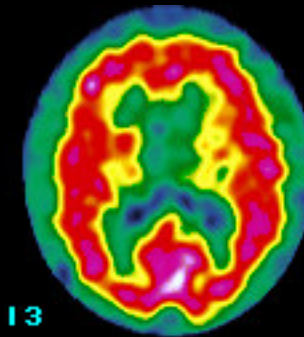
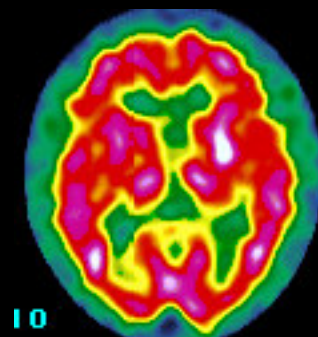
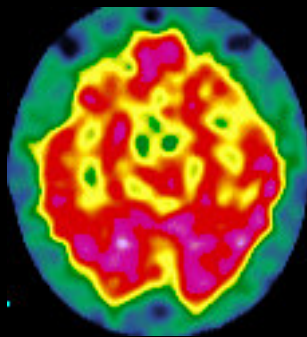
- primary photon (collimator response)
- scattered photon (scatter and collimator response )
- absorbed photon (absorption)

G. El Fakhri et al. "Relative impact of scatter, collimator response, attenuation, and finite spatial resolution corrections in cardiac SPECT", *J Nucl Med* 2000, vol. 41, pp. 1400-1408.

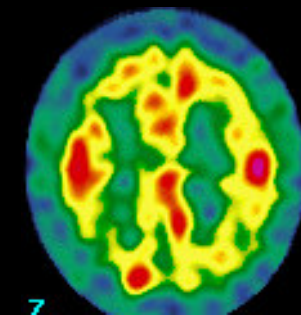
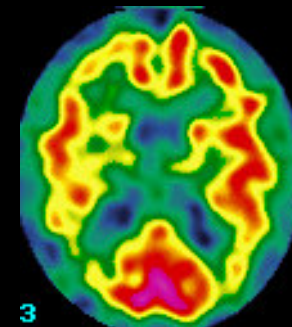
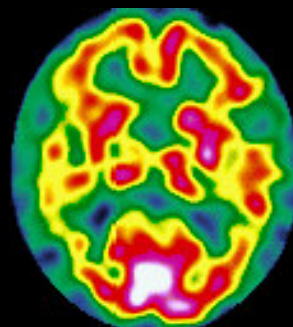
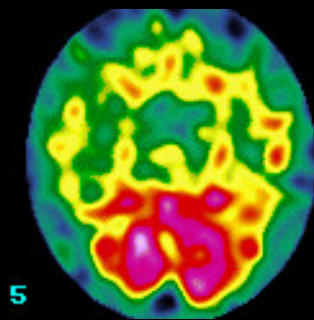
# Brain SPECT

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Normal



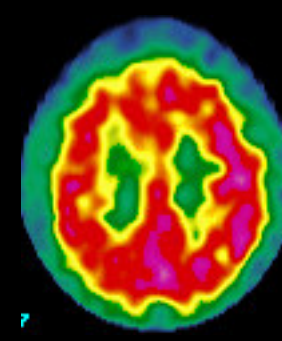
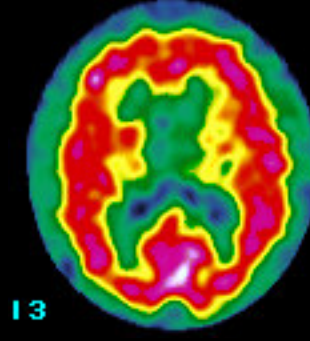
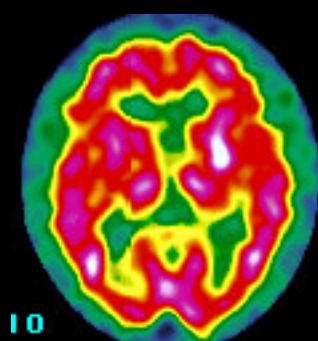
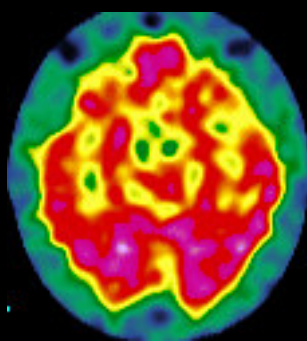
Alzheimer



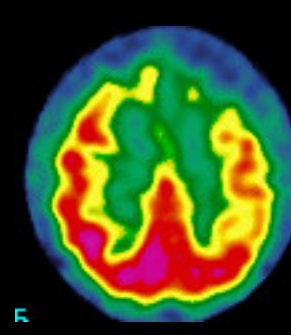
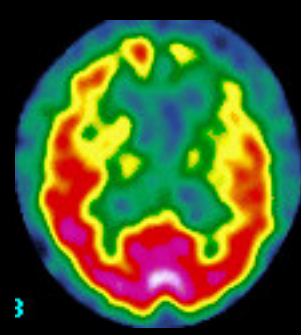
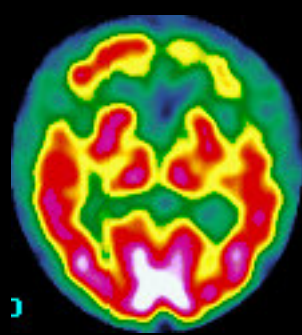
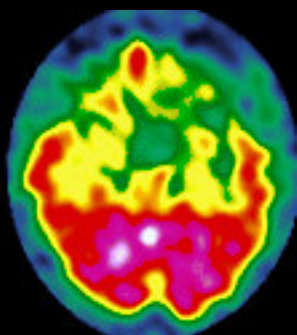
# Brain SPECT

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Normal



Frontal Lobe Dementia





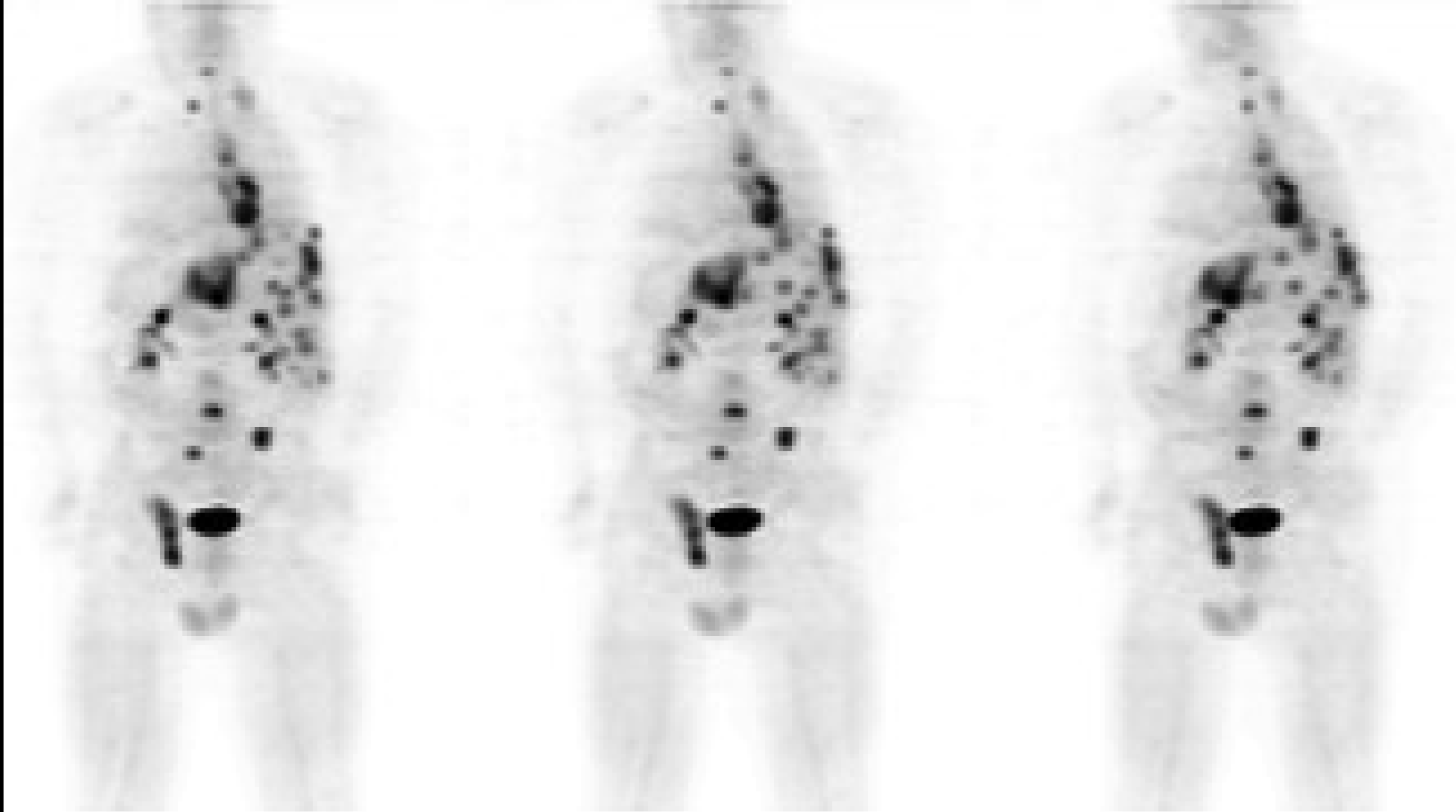
# Oncology PET – $^{18}\text{F}$ FDG

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**57 years old male, Lung Nodule D 1 cm**  
**Hypermetabolic nodule : cancer**  
**No adenopathy, no metastasis : possible surgery**  
**FDG : 15 mCi ; 15 min**

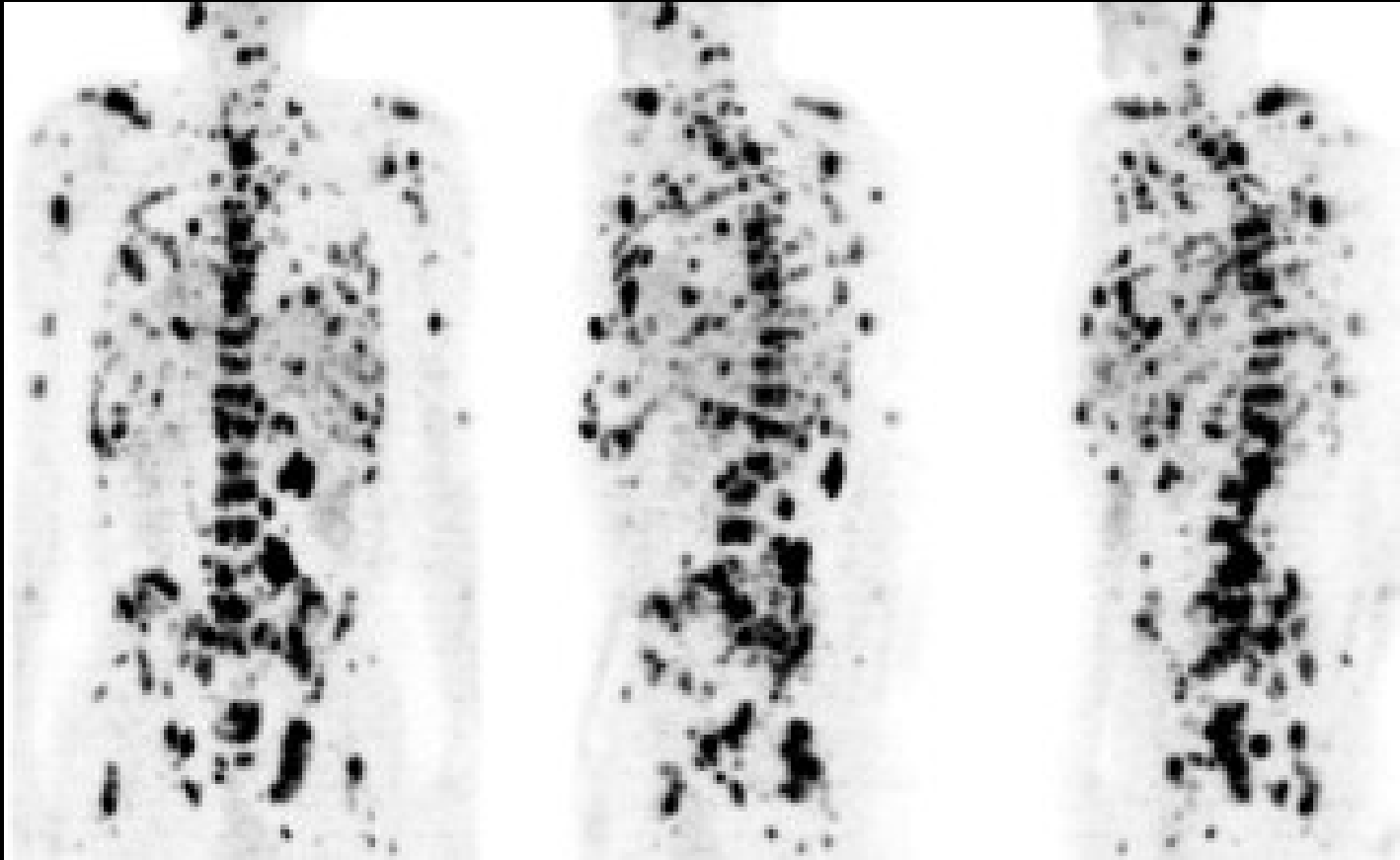
# Oncology PET – $^{18}\text{F}$ FDG



**57 years old male, lung cancer**  
**Ganglionic hepatic and bony metastases**  
**FDG : 5 mCi ; 7 x 7,5 min**

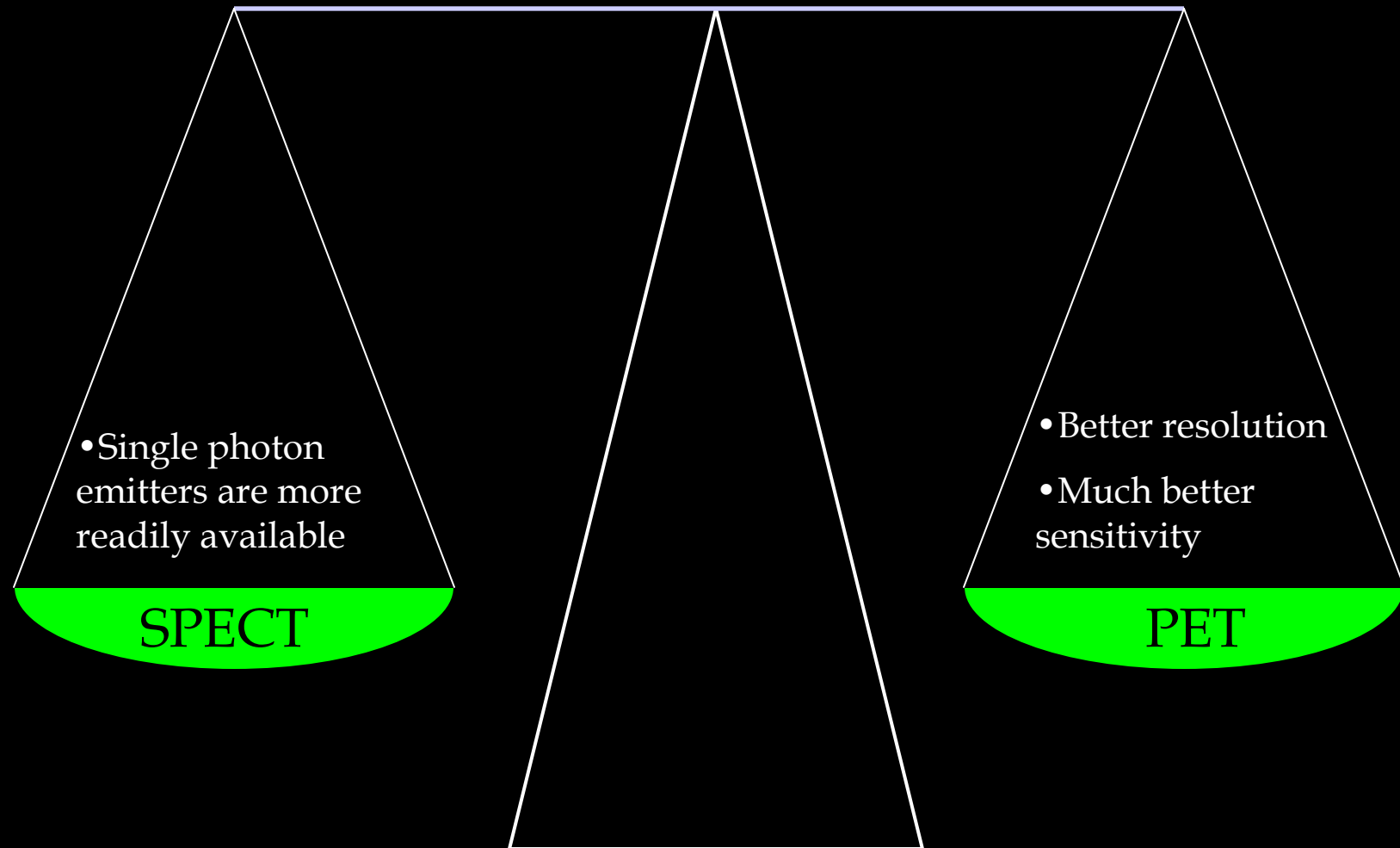
# Oncology PET – $^{18}\text{F}$ FDG

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**68 year old male, pancreatic cancer and melanoma**  
**Ganglion, bone and diffuse metastases**  
**FDG : 10 mCi ; 13 min**





Is there an ideal Nuclear Medicine camera ?

# Is there an ideal Nuclear Medicine camera ?

- Electronic collimation
- Single photon emitter

# Is there an ideal Nuclear Medicine camera ?

- Electronic collimation
- Single photon emitter

Yes, there is



NASA/JPL-  
Caltech

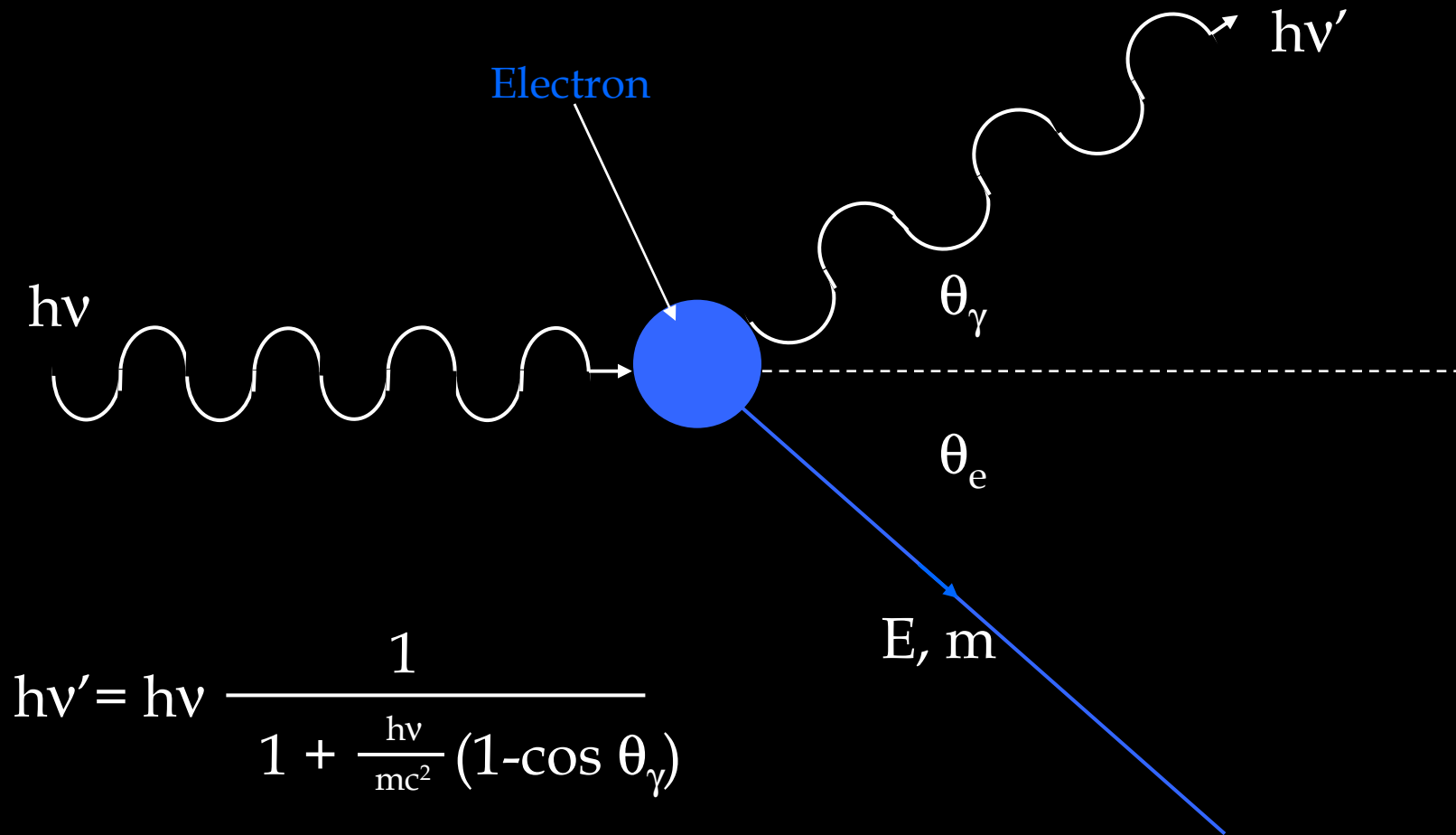




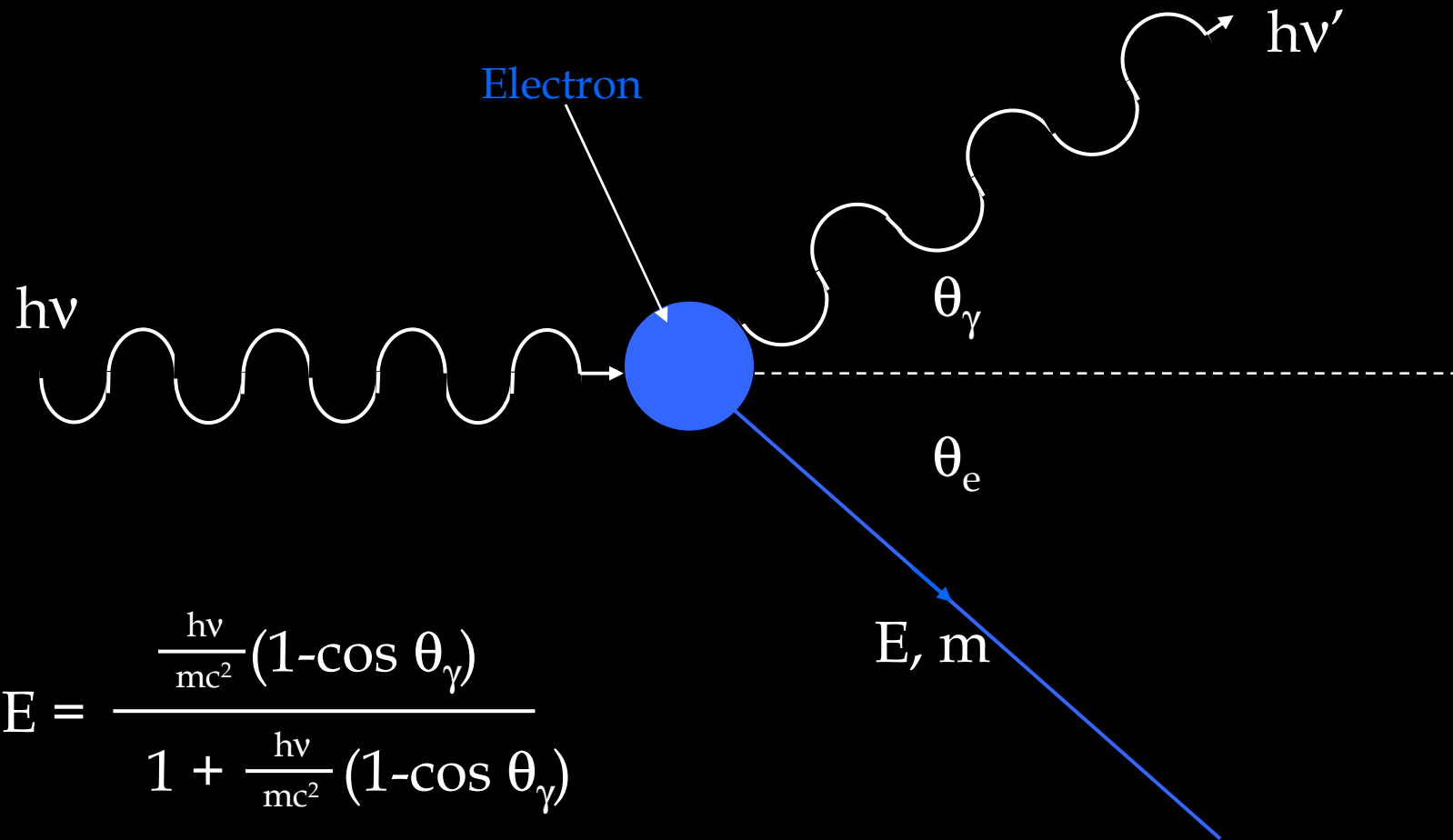
# Compton Camera

NASA/JPL-  
Caltech

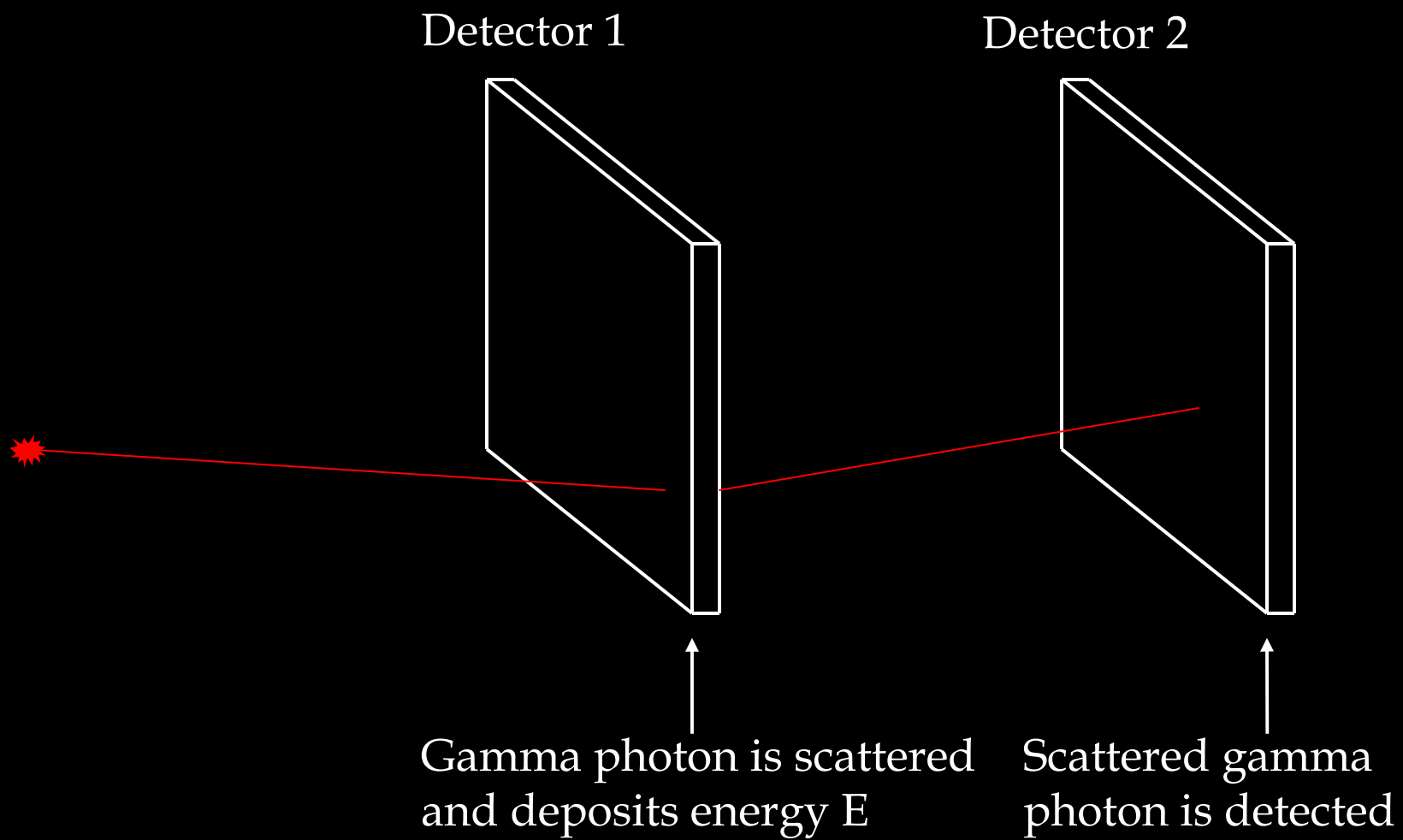
# Physics 101-Compton Scattering



# Physics 101-Compton Scattering

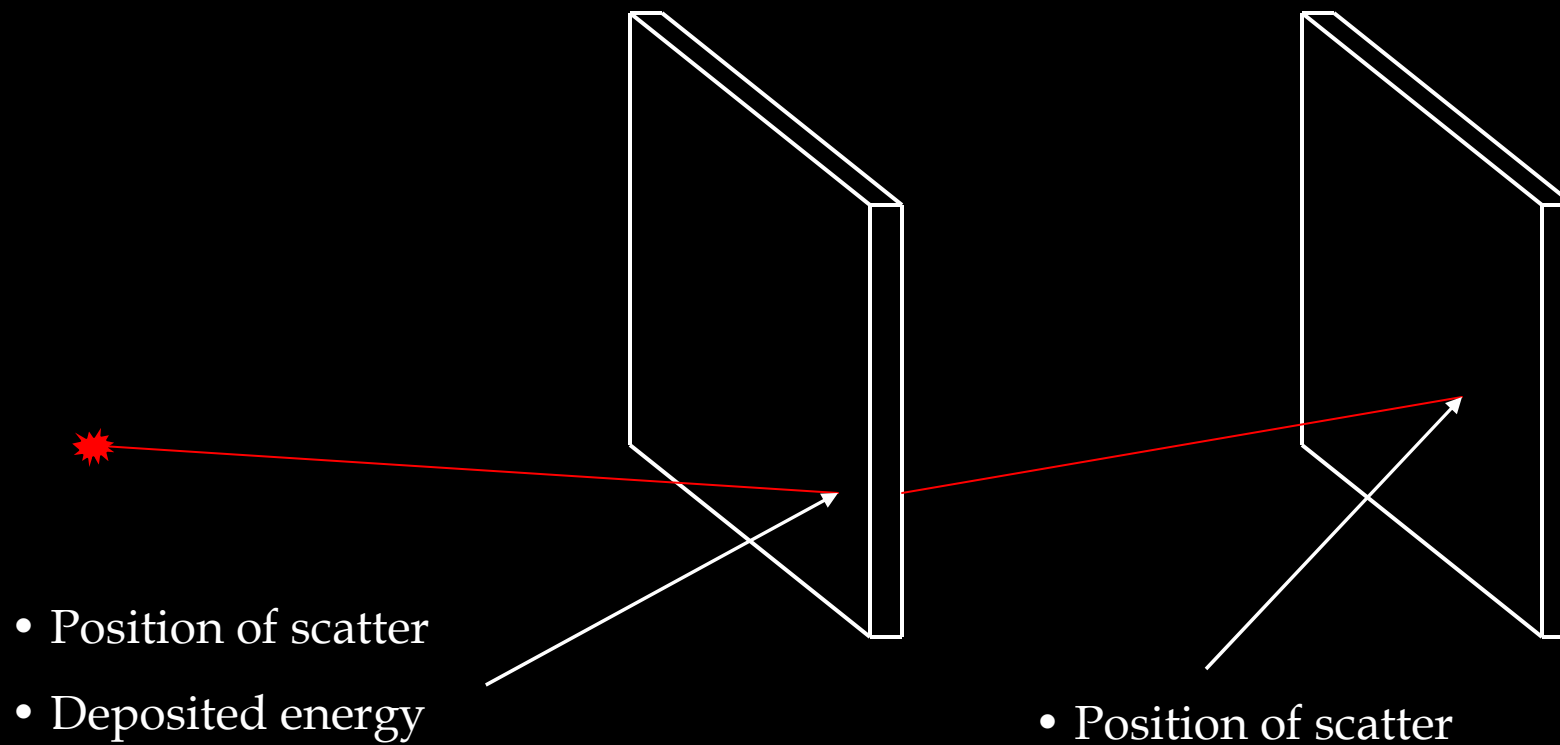






Detector 1

Detector 2



Physics 101

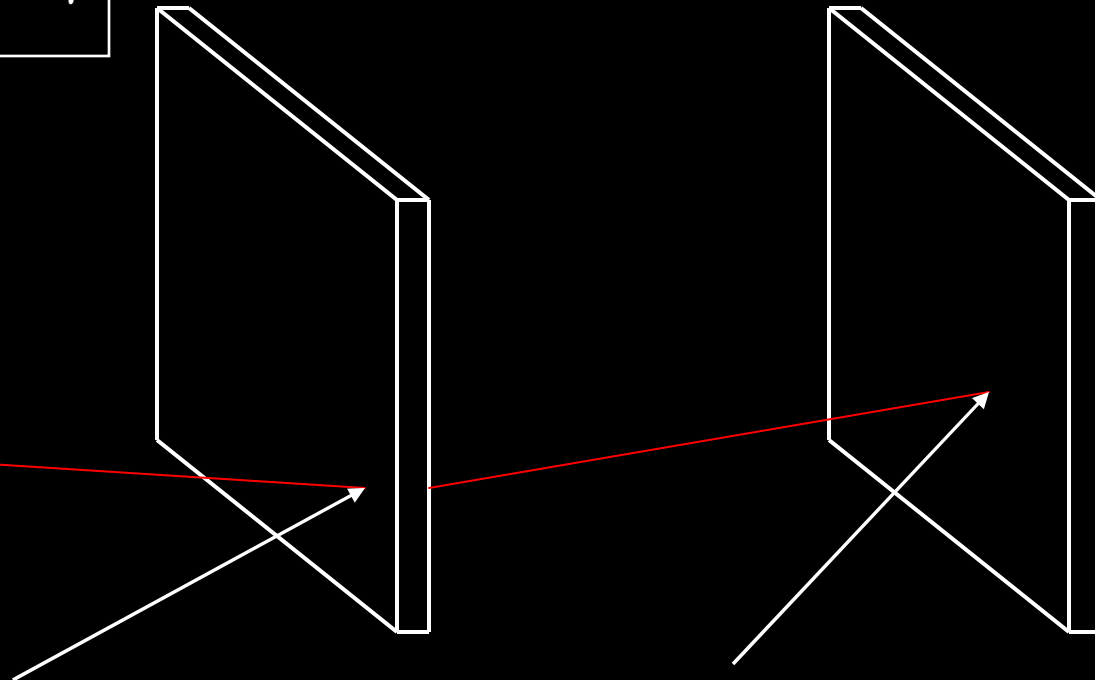
$$E = \frac{\frac{h\nu}{mc^2}(1 - \cos \theta_\gamma)}{1 + \frac{h\nu}{mc^2}(1 - \cos \theta_\gamma)}$$

Detector 1

Detector 2



- Position of scatter
- Deposited energy E



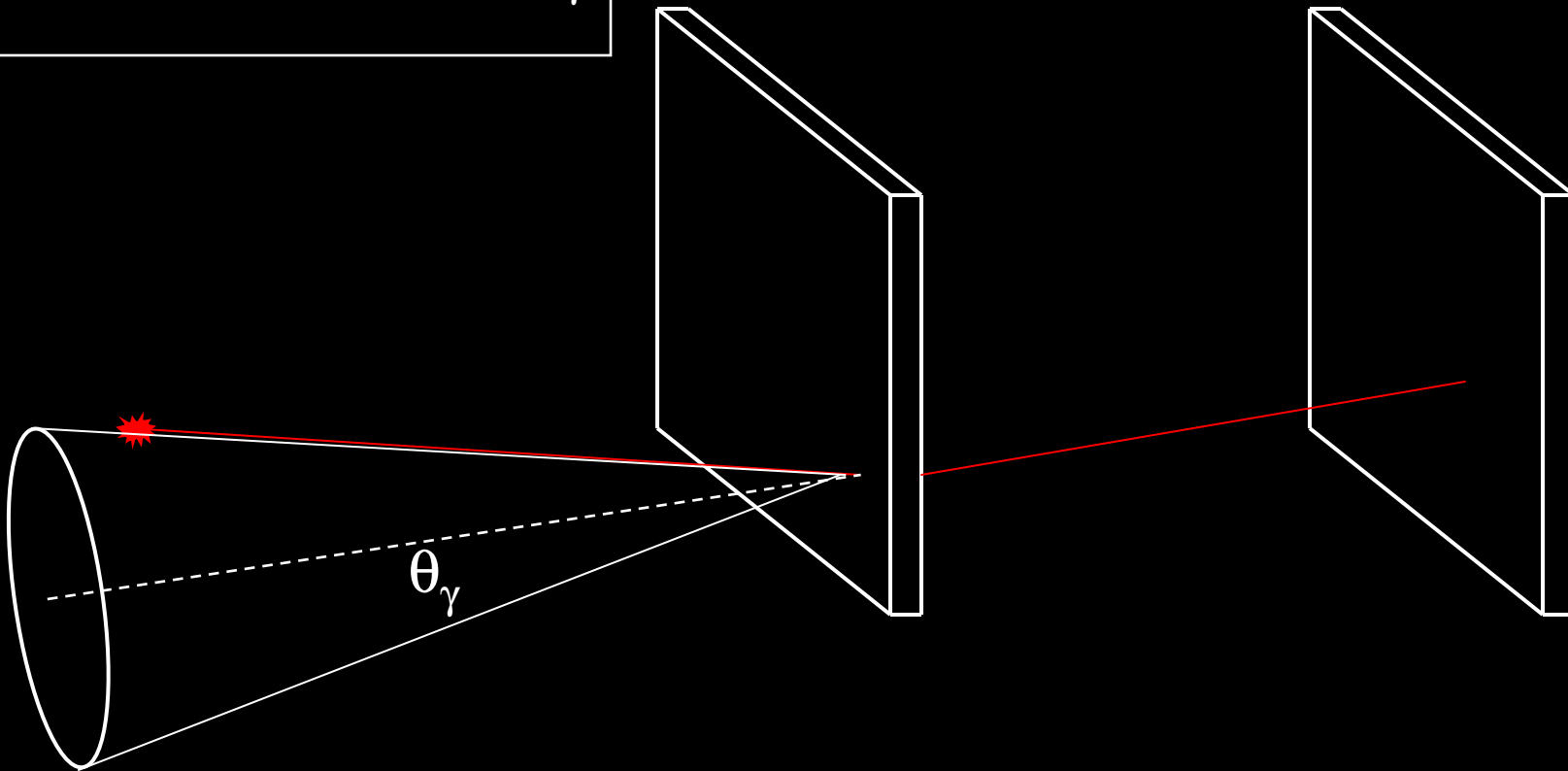
- Position of scatter

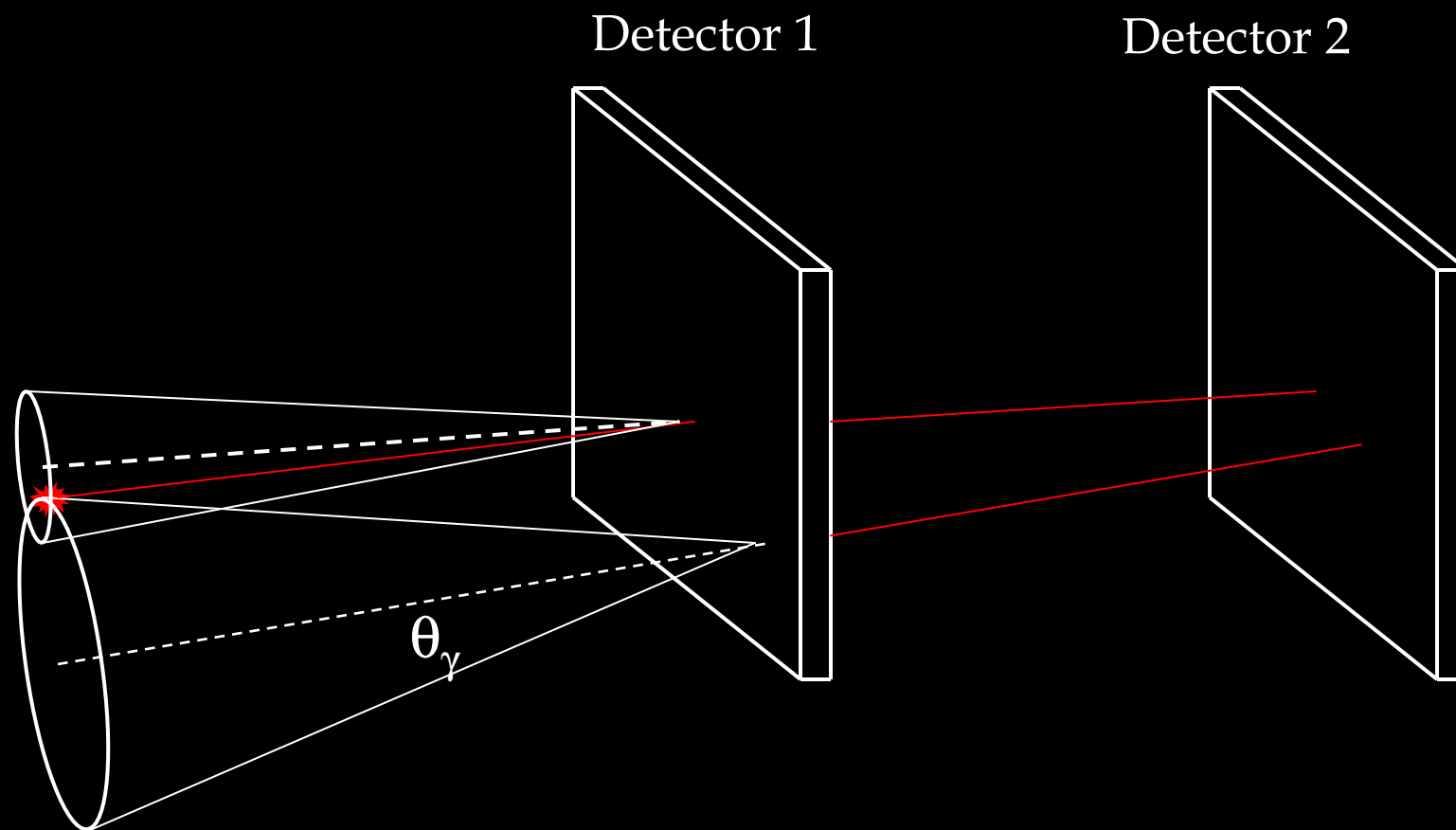
Physics 101

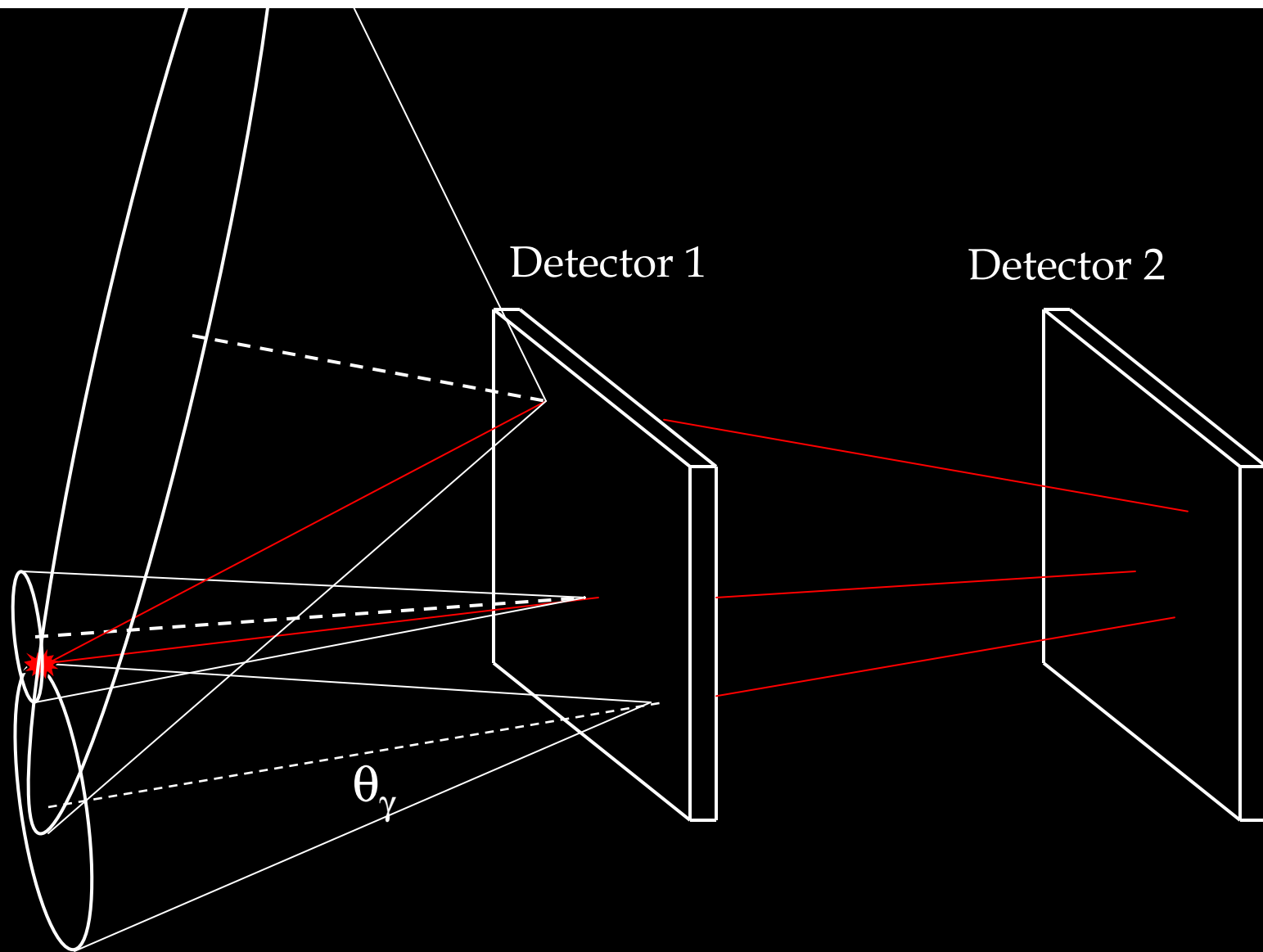
$$E = \frac{\frac{h\nu}{mc^2} (1 - \cos \theta_\gamma)}{1 + \frac{h\nu}{mc^2} (1 - \cos \theta_\gamma)}$$

Detector 1

Detector 2







# Challenges still to overcome

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- Detector 1 need to have VERY good energy resolution

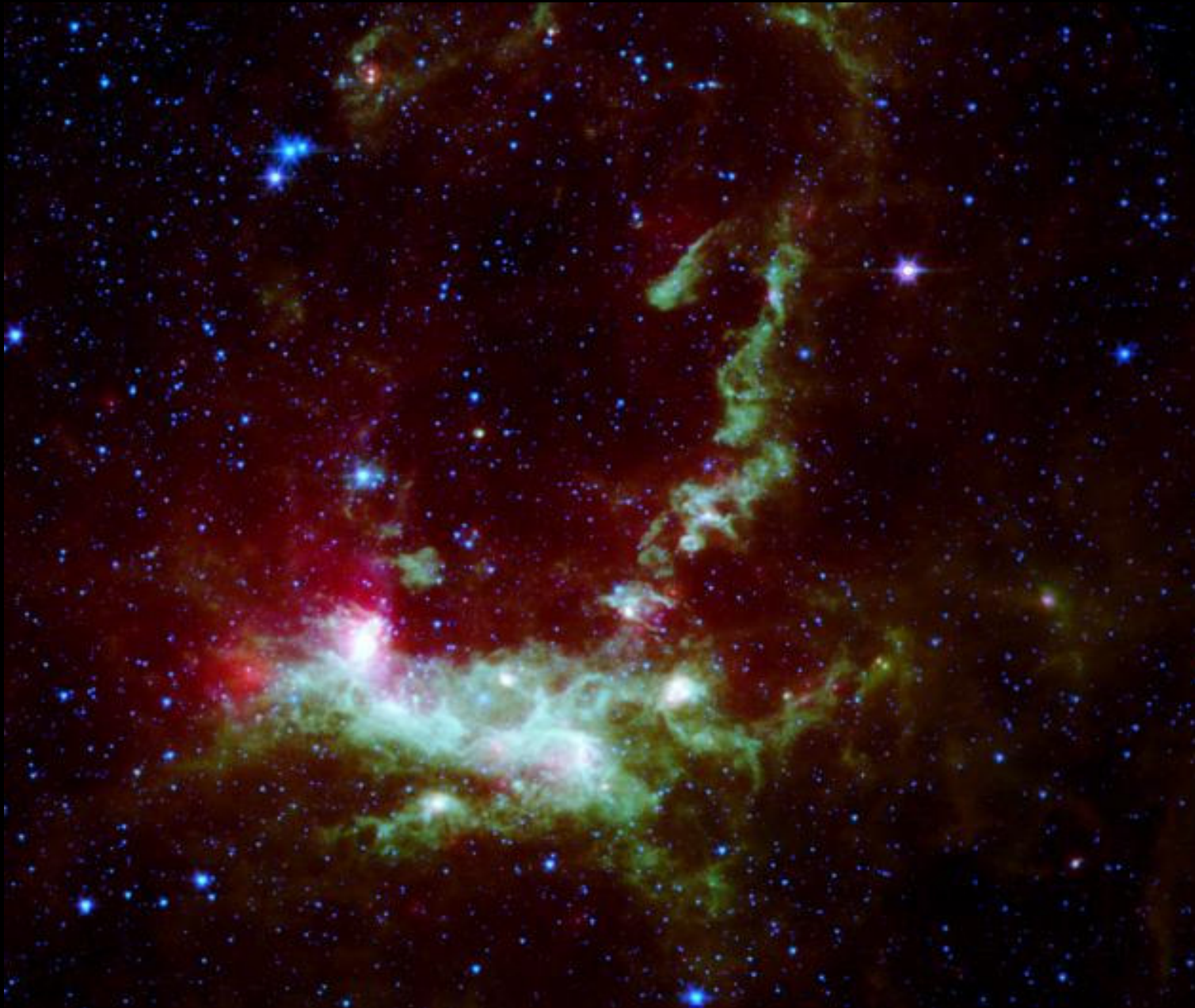
Solid state (semiconductor) detectors  
need to be used

# Challenges still to overcome

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- In order to reconstruct the distribution of radioactivity from “Compton cones” HUGE inverse problem needs to be solved





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